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FLOOD MODELING STUDY

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SILVER BOW CREEK

FLOOD MODELING STUDY

Prepared for

STATE OF MONTANA
DEPARTMENT OF HEALTH AND ENVIRONMENTAL SCIENCES
Helena, Montana

Prepared by

CH2M HILL
Boise, Idaho

November 30, 1989
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EXECUTIVE SUMMARY

Hydrologic, hydraulic, and sediment transport modeling studies of Silver Bow Creek were performed for the State of Montana, Department of Health and Environmental Sciences. The purpose of these studies was to evaluate the effects of the 10-, 25-, 100-year, and Probable Maximum Flood (PMF) events on the Silver Bow Creek System. The study reach includes about 30 miles of the stream, from the confluence of Silver Bow Creek with Warm Springs Creek near Anaconda, upstream to Butte, Montana.

Computer models were developed by CH2M HILL to simulate various natural elements of the drainage area during flood events. These elements included precipitation versus runoff (hydrologic), water surface elevations and flooded area (hydraulic), and sediment transport capacity of Silver Bow Creek during the above mentioned floods.

Computer programs used for the Silver Bow Creek studies were the HEC-1, a hydrologic program which simulates the precipitation, snowmelt, and runoff process; the HEC-2, a hydraulics program which calculates water surface elevations, velocities, and backwater elevations for given flood flows; and FLUVIAL-12, a sediment transport program which calculates sediment transport capability for streams during given flood events.

Models were calibrated where data were available for recorded flood events and then used to predict values for the 10-, 25-, 100-year, and PMF flows and related hydrologic, hydraulic, and sediment transport parameters. This report provides values for these flood events at various points along Silver Bow Creek upstream to Butte. Maps provided as appendixes show the lateral extent of the 100-year flooded area as calculated in the hydraulic analyses. These maps show the area that would be flooded during the 100-year flood.

For the hydrologic analyses, calculated peak flow values on Silver Bow Creek at the diversion location upstream of Mill and Willow Creeks for the 10-, 25-, and 100-year floods were 2,200, 2,800, and 4,000 cubic feet per second (cfs), respectively. Values which would include flows from Mill and Willow Creeks for the same events would be 2,490, 3,480, and 4,950 cfs, respectively.

Flows calculated for the PMF ranged from 108,000 to 169,000 cfs above Mill and Willow Creeks, and 129,000 to 201,000 cfs below Mill and Willow Creeks.

Sediment volumes transported along Silver Bow Creek that would reach the ponds' diversion location for the 10-, 25-, 100-year floods were calculated to be 25,000, 50,000, and 100,000 cubic yards, respectively. No sediment transport value was calculated for the PMF flow.

This report provides detailed results of the above studies and is meant to provide input for the State of Montana's ongoing feasibility studies.

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INTRODUCTION

AUTHORITY

This report summarizes the Silver Bow Creek flood modeling study that was conducted by CH2M HILL as part of the State of Montana's ongoing RI/FS of the Silver Bow Creek area. The report fulfills the requirements of Task Orders 16, 21, and 43 of a contract with the State of Montana, Department of Health and Environmental Sciences (MDHES).

The extent of heavy metals contamination present along Silver Bow Creek led the U.S. Environmental Protection Agency (EPA) to designate the Butte-Silver Bow Creek area as a high priority Superfund site in 1983. The Solid and Hazardous Waste Bureau (SHWB) of the Montana Department of Health and Environmental Sciences administers the site under a cooperative agreement with the EPA. Most of the remedial investigation (RI) work has been completed and feasibility studies (FS) are commencing.

The flood modeling study on Silver Bow Creek will provide computer models that are needed to evaluate the various remedial alternatives that will be considered for this site. These models are capable of simulating the hydrologic and hydraulic characteristics of Silver Bow Creek at various flood stages, including peak flow values during specific

flood frequencies and the associated flooded areas and sediment transport capabilities for these events.

PURPOSE AND SCOPE

The general purpose of this study was to develop 10-, 25-, 100-year, and Probable Maximum Flood (PMF) hydrographs and related flood data along Silver Bow Creek from Butte, Montana, downstream to just below the Warm Springs Pond 2 outflow near Warm Springs Creek. These hydrographs and calculated peak flow values were then used to estimate sediment transport capability during the 10-, 25-, and 100-year flood events. Topographic maps at a scale of 1:2400 with 2-foot contours were also prepared for the Silver Bow Creek floodplain area. These maps and calculated water surface elevations were utilized to show flooded areas during the 100-year flood for the entire study reach along Silver Bow Creek. Potential flood detention reservoir sites were located within Silver Bow Creek drainages for possible future flood mitigation measures. These above data would then be used to support the State of Montana's subsequent feasibility studies for remedial activities in the Silver Bow Creek study area.

This flood modeling study and related field and laboratory work was conducted in accordance with procedures outlined in the Silver Bow Creek Flood Modeling Study's Quality Assurance Project Plan (QAPP) dated June 30, 1987; Field

Operation Plan (FOP) dated June 30, 1987; and the Laboratory Analytical Protocol (LAP) dated June 30, 1987. All data collected and subsequently used in this study met all quality assurance requirements as outlined in the QAPP.

SITE HISTORY

Silver Bow Creek originates on the western slope of the Continental Divide, north of the City of Butte, Montana. It drains an area covering approximately 425 square miles before forming the Clark Fork River at its confluence with Warm Springs Creek (Figure 1).

Mining in the Butte area began with the discovery of placer gold in Silver Bow Creek in late summer 1864. Several townsites and camps sprang up among the diggings; however, these operations were short-lived and most of the miners left the area by 1869. Those who stayed began prospecting the quartz lode deposits of silver and the associated complex copper ores on Butte Hill. Their efforts culminated in a silver rush that began in the mid-1870s and revived the Butte area. During that time world-class deposits of copper ore were identified.

By 1881 Butte had become one of the nation's major mining centers and the district attained national prominence by the turn of the century. By 1915 Anaconda Copper Mining Company led the industry; but in 1980, in response to a depressed

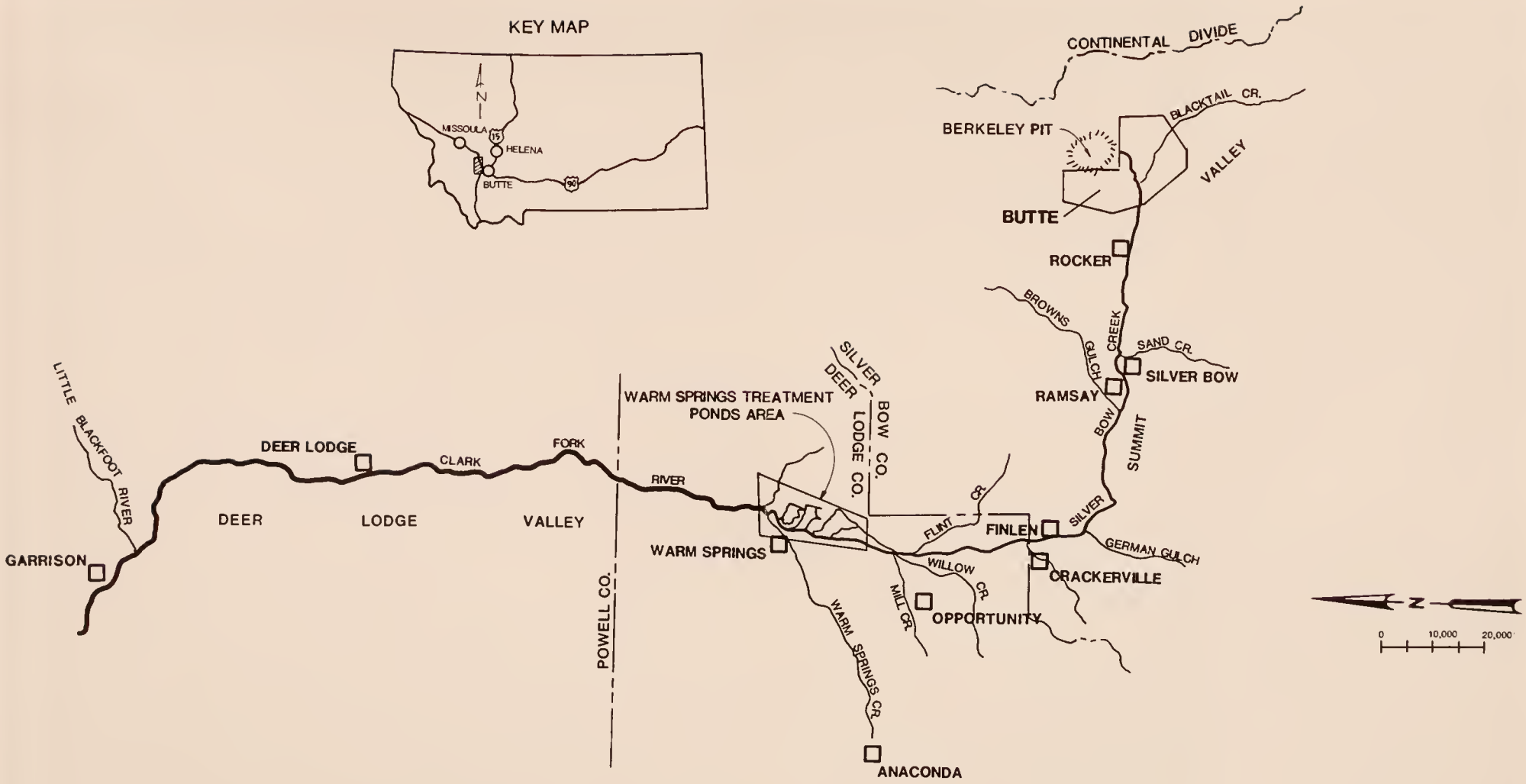

Figure 1
VICINITY MAP
SILVER BOW CREEK FLOOD MODELING STUDY

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copper market, Anaconda closed all the underground mines and continued active mining only in the Berkeley Pit (established in 1955). In 1977 Anaconda became a subsidiary of Atlantic Richfield Company (ARCO). ARCO closed the Berkeley Pit in 1982 and the East Berkeley Pit in 1983.

The history of over 100 years of continuous mining and related activities greatly changed the area's natural environment. Early mining, milling, and smelting wastes were dumped directly into Silver Bow Creek and transported naturally downstream to the Clark Fork River. This had severe environmental effects along the creek and its immediate surroundings.

In 1911 a treatment pond was built by Anaconda Company near Warm Springs, Montana, to settle out the mine wastes from Silver Bow Creek before the water was allowed to move on to the Clark Fork River. Two additional treatment ponds have since been constructed; one in 1916 and the other in 1959.

Silver Bow Creek upstream of the treatment ponds received raw mining and milling wastes until 1972 when a treatment plant was added to the Weed Concentrator in Butte. Creek contamination problems were compounded by urban and domestic sewage, wood products treatment plants, phosphate and manganese production facilities, and chemical factories. Mill tailings, mining wastes, and other wastes in and near the creek contribute to substantial downstream contamination; particularly by the elements arsenic, cadmium, copper,

lead, iron, and zinc. These elements and others were present in the ore that was removed from the mines and remained in the byproducts of the milling and smelting processes.

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Silver Bow Creek is located in Southwestern Montana, west of the Continental Divide near the city of Butte, in the Northern Rocky Mountain physiographic province. The site contains several population centers; the largest is the City of Butte and the second largest is Deer Lodge. Numerous small communities are situated along Silver Bow Creek and the upper Clark Fork River, including Rocker, Silver Bow, Ramsay, Crackerville, Opportunity, and Warm Springs (Figure 1).

GEOLOGY

The geology of the Silver Bow Creek area is diverse, with rocks ranging from Cretaceous intrusive to Quaternary alluvium. Rocks are largely siliceous, with zones containing valuable mineral deposits. A distinct change in the orientation of valleys in the study area is evident: the Summit Valley trends generally east-to-west, whereas the Deer Lodge Valley is oriented north-to-south.

In the eastern portion of the study area near Butte, the Boulder Batholith is composed primarily of highly mineralized quartz monzonite. Gold, silver, and copper, and lesser quantities of cadmium, bismuth, arsenic, selenium, and

tellurium have been produced from this deposit within the Butte Mining District (Ref. 1).

The Deer Lodge Valley and the upper Clark Fork River are bounded on the west by the Anaconda-Pintlar and Flint Creek mountain ranges, both of which contain significant amounts of limestone. This lithologic difference from the Summit Valley is reflected in both soil character and surface water and groundwater chemistry.

Tailings, waste rock, and smelter wastes are present at locations throughout the study area. These materials generally overlie natural colluvium and fractured (or occasionally undisturbed) bedrock.

SOILS

A diversity of soil types is present in the study area. Soils in the basins are developed primarily on upland slopes under coniferous forests and on valley fill sediments under grassland vegetation. Moderately deep soils have developed on alluvial fans and sediments (Ref. 2). In the valleys, gently sloping, deep soils have developed along terraces. Gravel-textured to deep, fine-grained alluvial soils have developed adjacent to Silver Bow Creek and the Clark Fork River. Shallow, nutrient-rich organic soils of various depths are present in some low or wetland areas.

Much of the natural soil in the study area has been affected by mining wastes. Natural soils have been disturbed in the Butte area where mill tailings, smelter wastes, and mine waste rock are present. Many areas along Silver Bow Creek and the Clark Fork River floodplain are covered with waste materials.

These mining-related wastes are generally sandy textured, reflecting their granitic origin, and typically have high concentrations of metals and sulfide minerals. Accumulation of bioavailable heavy metals severely limits vegetation establishment which, in turn, limits soil development.

CLIMATE

The Silver Bow Creek study area has a continental climate characterized by short, cool, dry summers and cold winters. Average mid-winter temperatures are well below freezing, and mid-summer temperatures average between 60 and 65°F. Annual precipitation in Butte varies from 6 to 20 inches, averaging approximately 12.0 inches (Figure 2). Annual precipitation patterns in the upper Clark Fork Valley are similar to those in Butte; the average annual precipitation in Anaconda is 13.2 inches. Generally, 50 percent of the annual precipitation in the Butte-Anaconda area falls in late spring and early summer.

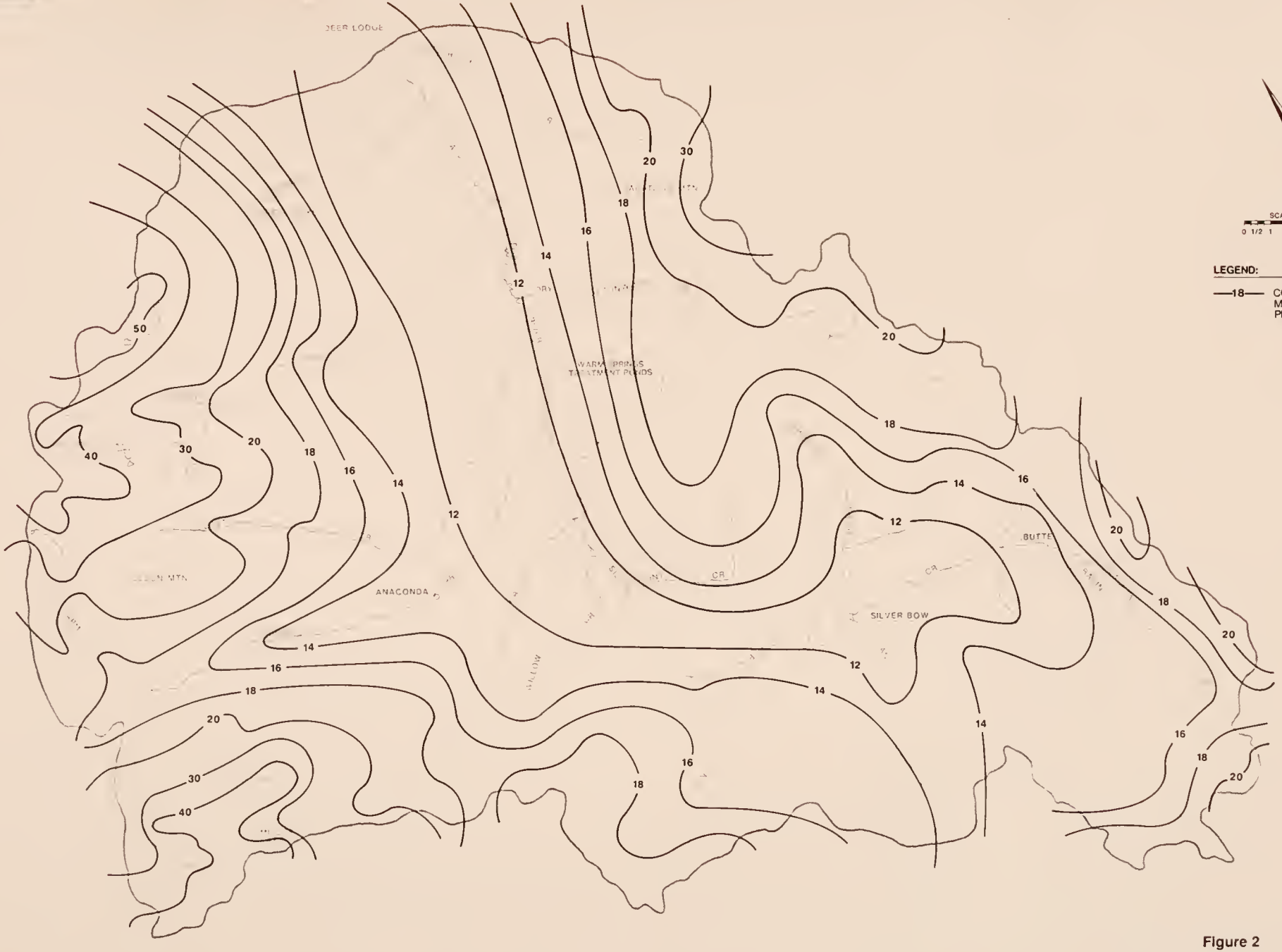

Figure 2
MEAN ANNUAL PRECIPITATION
SILVER BOW CREEK FLOOD MODELING STUDY

Climate in the higher mountain elevations surrounding the study area is alpine to subalpine. This climate is characterized by colder temperatures and heavier precipitation, as shown in Figure 2. This heavier precipitation is often in the form of snow. Melting of the mountain snowpack in spring and early summer provides the majority of the annual streamflow within the study area.

Streams in the area become partially to fully ice-covered during the winter months. The area occasionally experiences warm chinook (westerly descending) winds, which cause mid-winter thaws and subsequent high streamflows. Snow cover in the lower valleys usually melts in March to early April, with the mountain snowpack normally remaining through May and into June.

VEGETATION

The vegetation in the Silver Bow Creek watershed varies considerably from grasslands at the lower elevations to coniferous forests on the higher slopes. The floodplain vegetation includes an overstory of cottonwood, willow, and alder with an understory of reedgrass, mana grass, and tall wheatgrass; rushes and cattails are found where the water table is near the ground surface.

Areas that are covered with tailings deposits are nearly devoid of plant life; the limited vegetation is a sparse, weedy community of inland salt grass and scorpion plant.

LAND USE

The majority of the land within the Silver Bow Creek watershed is used for the grazing of livestock. Smaller areas are used for irrigated agriculture and industrial purposes. The higher, forested areas are used for recreational activities and limited logging.

Industrial uses, while limited in terms of land area, have had the largest impact on Silver Bow Creek of any of man's activities within the watershed.

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PREVIOUS FLOOD-RELATED STUDIES

A literature review was conducted to identify previous investigations for which flood flows were calculated for Silver Bow Creek and various tributaries that are of concern to this flood modeling investigation. Following is a brief review of each of the three studies of interest that were identified.

INTERNATIONAL ENGINEERING COMPANY REPORT

International Engineering Company (IECO) evaluated the effect of a Probable Maximum Flood (PMF) from Silver Bow Creek on the Warm Springs Ponds in Ref. 3. The calculated PMF peak at the diversion into Pond 3 was estimated at 117,200 cfs with a total volume of 191,000 acre-feet. Flow entering the ponds in excess of 5,600 cfs would cause the overtopping of Pond 3; floods in excess of 7,000 cfs would overtop Pond 2; and flows in excess of 7,500 cfs would overtop all three ponds. The Mill-Willow bypass channel was estimated to have a flow capacity of 4,000 cfs; the decants of Pond 3 approximately 1,600 cfs; and the outlet of Pond 2 1,400 cfs. It was also predicted that the overtopping of any of the embankments could cause embankment failure by erosion.

PMF flows from the drainages into the ponds along east side canyons are presented in Table 1. These data show that Pond 3 would contain the PMF conditions, but Ponds 1 and 2 would both be overtopped and probably fail.

Table 1
PMF PEAKS FROM EAST SIDE DRAINAGES
FOR WARM SPRINGS PONDS*

Pond	PMF Peak Discharge (cfs)	PMF Volume (acre-feet)	Surcharge Capacity (acre-feet)
1	13,800	2,200	1,600
2	19,200	3,000	1,000
3	9,700	1,000	4,000

*Data from IECO Report, March 1981

FLOOD INSURANCE STUDY:
BUTTE-SILVER BOW, MONTANA

Morrison-Maierle, Inc., conducted a hydrologic and hydraulic analysis of Silver Bow Creek for the Federal Insurance Administration in 1979 (Ref. 4). As part of the study, peak flow estimates for the 10-, 50-, 100-, and 500-year return period floods were estimated for Silver Bow Creek and some of its tributaries. These estimated peak flows are presented in Table 2.

Table 2
SUMMARY OF DISCHARGES, FLOOD INSURANCE STUDY*

Flooding Sources and Location	Drainage Area (sq mi)	Peak Discharges (cfs) 10-Year	50-Year	100-Year	500-Year
Silver Bow Creek					
At Fairmont Hot Springs	323.7	1,672	2,402	2,763	3,854
At the Town of Rocker	118.0	833	1,217	1,413	1,989
At Montana Avenue	103.8	683	997	1,158	1,630
At Confluence with Blacktail Creek (Cross Section C)	21.8	104	153	179	232
Gregson Creek					
Below Butte, Anaconda and Pacific Railroad	4.3	28	33	41	44
Above Butte, Anaconda and Pacific Railroad	4.3	80	98	119	178
Blacktail Creek					
At Mouth of Blacktail Creek	97.8	666	976	1,136	1,583
At Cross Section D	87.7	538	763	850	1,105
At Cross Section J	32.7	343	524	619	896
At Cross Section L	32.1	317	484	571	827
At Cross Section P	31.7	298	458	543	786
At Cross Section R	31.4	273	420	498	722
At Cross Section T	26.8	225	346	410	594
At Confluence with Little Blacktail Creek	22.8	173	270	322	468
Grove Gulch Creek					
At Mouth	6.5	76	87	95	113
Above Tailings Pile	5.0	84	136	164	245
Sand Creek					
At Mouth	8.2	79	137	188	346
At Cross Section P	5.8	101	166	201	300

Table 2 (Continued)
SUMMARY OF DISCHARGES, FLOOD INSURANCE STUDY*

Flooding Sources and Location	Drainage Area (sq mi)	Peak Discharges (cfs) 10-Year	50-Year	100-Year	500-Year
Basin Creek	47.3	281	370	386	433
At Mouth	47.3	255	330	340	367
At Cross Section C	46.5	169	194	206	232
At Cross Section F	46.5	390	585	692	995
Above Airport Pipe					
At Confluence with Little Basin Creek	37.9	290	443	523	758
At Cross Section T					
Reese Canyon	1.0	18	30	37	56
At Mouth					
Tramway Gulch	0.7	12	20	25	38
At Mouth					
Brookside Canyon	1.5	26	45	54	82
At Mouth					
Mode-S Canyon	1.7	25	41	50	75
At Mouth					
Big Hole River	2,362.0	12,300	16,542	18,261	22,072
Near Melrose					

*Data from Flood Insurance Study produced by Morrison-Maierle, Inc., March 1979.

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FLOOD HAZARD ANALYSIS: WARM SPRINGS CREEK

The Soil Conservation Service (SCS) performed a flood frequency analysis of Warm Springs Creek near Anaconda in June 1976, developing peak flow values for the 10-, 50-, 100-, and 500-year return periods (Ref. 5). These values were used in a hydraulic analysis to estimate flooded areas at various cross sections along Warm Spring Creek. Flows developed for the mouth of the creek are listed in Table 3.

Table 3
SUMMARY OF DISCHARGES, WARM SPRINGS CREEK,
SCS FLOOD HAZARD ANALYSES*

Return Period (Years)	Flow (cfs)
10	870
50	1,250
100	1,430
500	1,865

*Data from SCS Flood Hazard Analyses--Warm Springs Creek, June 1976

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FLOODING HISTORY

Damaging floods have occurred in the Clark Fork River drainage since the settling of the area in the mid-1860s. Historical records show that for watersheds greater than a few tens of square miles, yearly maximum flows occurred from spring snowmelt augmented by rainfall or, more rarely, winter chinooks with snowmelt and rain on frozen ground.

On smaller watersheds, maximum flows are produced by rain on frozen ground in winter, or by cloudbursts during thunderstorms in summer. Thunderstorms produce high intensity rainfall events but are very localized and, therefore, the resulting peak streamflows are attenuated rapidly with distance.

The largest known flood since the upper Clark Fork Basin was settled occurred in June 1908. Heavy rains fell in late May and early June, melting the snow pack and causing extensive flooding. The amount of rain in Butte for the period is presented in Table 4. Snow cover in the mountains during the June 1908 storm was not measured, but preceding cold, wet conditions in April and May would have created above normal snow packs at higher elevations. Newspaper accounts stated that there were 9 inches of snow on the ground in Butte the morning of June 5. Also during this storm, power lines were down because of the heavy snows.

Table 4
HISTORICAL PRECIPITATION DATA IN BUTTE DURING THE 1908 FLOOD

Date	Total Daily Rainfall (inches)
May 19	0.70
May 22	0.40
May 25	0.40
May 26	0.70
May 29	0.70
May 30	0.70
May 31	0.90
June 1	0.37
June 2	0.45
June 3	0.70
June 4	0.50
June 5	1.60

WINTER FLOODS

Major winter floods can be caused by a rare combination of frozen ground (concrete frost) and rapid snowmelt induced by warm temperatures and sometimes localized rain. The locations of areas covered by frozen ground vary widely from year-to-year in response to snow accumulation and freeze/thaw cycles. Early snows of significant depth limit the formation of frozen ground. Too little snow or the absence of melt cycles restrict the moisture content in the soil and little frozen ground forms. Therefore, frozen ground does not occur every year and usually covers a limited elevation range.

A very strong low latitude upper air trough off the Pacific coast can induce strong southwest surface winds and rapid warming of air temperatures in western Montana (chinook conditions). However, the orientation of the upper air flow parallel to the Continental Divide and perpendicular passage over the Bitterroot Range causes moisture levels and precipitation to be low in the Silver Bow Creek basin, even while heavy rainfall is occurring in Idaho. Recent events of this type occurred in December 1964, January 1974, and February 1986. High runoff occurred from limited elevation zones where the combination of frozen ground and snow depth was optimum.

In December 1964 high winds and warm air temperatures caused the flood of record on Smith Gulch southwest of Butte, and high runoff occurred from other portions of the 6,000- to 7,000-foot elevation zone of the Silver Bow Creek basin.

In January 1974 high winds, warm air temperatures, and localized rainfall caused high runoff from portions of the 5,000- to 6,000-foot elevation zone on Warm Springs Creek and Mill and Willow Creeks.

In February 1986 high winds and warm air temperatures caused high runoff from the 4,000- to 5,000-foot zone in the lower Clark Fork basin. In none of these events was runoff extensive enough to cause severe flooding on Silver Bow Creek upstream of the Warm Springs Ponds.

The wide range of elevation in the Silver Bow Creek basin makes it quite unlikely that extensive areas of frozen ground would be present and create unusual runoff conditions. This type of flood represents the 100-year and greater recurrence event for many river basins in the western states between the Cascades and the Rocky Mountains. In researching historical climatological, newspaper, and streamflow recording station records from the 1860s to the present, no major runoff event in the Upper Clark Fork River Basin (including Silver Bow Creek) was caused by intense rainfall on frozen ground. These records clearly show that the winter snowmelt rain on frozen ground event, for lower Silver Bow Creek, would not be representative of 10-, 25-, and 100-year design events due to less intense rainfalls and the limited area that contributed to runoff.

The January 1974 and February 1986 events were used to help calibrate the HEC-1 runoff model since extensive hydrologic and climatic data existed for those events.

SPRING FLOODS

In the spring snowmelt season, high sustained flows are generally associated with simultaneous melting of large snow-covered areas during periods of clear skies and warm temperatures in May and June. Clear-sky snowmelt has produced the greatest floods in large river basins (for example, Clark Fork near Missoula) for which a week or more of sustained high snowmelt runoff from all portions of the basin is required for flows to combine downstream and cause floods. Peak flows for

smaller basins (less than 5,000 square miles), are generally caused by rainfall on active snowmelt zones.

Upper atmospheric, closed low-pressure storm systems, characteristic of spring conditions, commonly follow tracks from the Pacific Ocean off Oregon into Nevada, then into Colorado or Montana. If the low-pressure system is blocked by a high-pressure ridge to the east, it can remain nearly stationary, eventually transporting moisture north from the Gulf of Mexico into Montana. Intense rainfall from storms of this type occurred in Montana in June 1975 and May 1981.

In the May 1981 event, the heaviest rainfall was localized over the Continental Divide north of Butte in the headwaters of Boulder River, Cottonwood Creek, Little Blackfoot River, and Ten Mile Creek west of Helena. The storm event of June 1975 covered a wider area of western Montana than the 1981 event, but snow cover with associated saturated ground conditions was more limited in extent. The greatest flood of record for most of the Clark Fork basin occurred in June 1908. The flood was caused by an unusual combination of extensive late-season snowpack and heavy rain.

Examination of all significant spring snowmelt/rain flood events (the largest events are shown in Table 5), indicates that these events were caused by the combination of heavy rain at high elevations and large areas of active snowmelt zone. All of the historic events of this type occurred from late April through early July, with most from mid-May to mid-June.

Table 5
HISTORIC FLOOD EVENTS
SILVER BOW/CLARK FORK BASIN AND VICINITY

Date	Type	Remarks
February 22-24, 1986	Winter Rain/Snowmelt on Frozen Ground	Largest known flooding from 4,000- to 5,000-ft elevations
May 22-23, 1981	Spring Rain/Snowmelt at High Elevations	Second largest flood north of Butte since 1908
May 25-26, 1980	Spring Rain/Snowmelt	Fourth largest since 1908; snowcover below normal
June 19-20, 1975	Spring Rain/Snowmelt at High Elevations	Second largest flood on Silver Bow Creek since 1908
January 15-16, 1974	Winter Rain/Snowmelt on Frozen Ground	Largest flood on Warm Springs Creek and at 5,000- to 6,000-ft elevations
June 8-10, 1972	Spring Clear Sky Snowmelt	Largest recorded flood on Big Hole River
December 23-24, 1964	Winter Rain/Snowmelt on Frozen Ground	Largest flood for 6,000- to 7,000-ft elevations. Much worse in Idaho and Pacific Northwest
May 23 - June 2, 1948	Spring Rain/Snowmelt at High Elevations	Third largest flood since 1908
March 28, 1943	Spring Snowmelt on Frozen Ground	Chinook caused largest flood for 5,000- to 6,000-ft elevations in Big Hole Basin
May 17-18, 1938	Spring Rain/Snowmelt at High Elevations	Fourth or fifth largest flood since 1908

Table 5 (Continued)
HISTORIC FLOOD EVENTS
SILVER BOW/CLARK FORK BASIN AND VICINITY

Date	Type	Remarks
June 4-6, 1908	Spring Rain/Snowmelt at Elevations Over 5,000 feet	Probably largest flood on Silver Bow/Clark Fork since 1870s
June 16-20, 1899	Spring Clear Sky Snowmelt	Large flood on Lower Clark Fork
June 12-14, 1898	Spring Clear Sky Snowmelt	Large flood on Lower Clark Fork
May 28 - June 4, 1894	Spring Rain/Snowmelt	Flooding reported in Butte/Silver Bow Creek
June 15-23, 1892	Spring Rain/Snowmelt	Flooding in Butte/Silver Bow Creek

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Snow course records indicated that for the largest events extensive snow cover was still present above the 7,000-foot elevations with some limited snow cover on north slopes at lower elevations. The events had similar antecedent snowmelt or rainfall, which created saturated snowpack and ground at high elevations. The soil infiltration rate for the active snowmelt zone under these conditions would be very low.

Historic records from newspapers, climatological data and streamflow recording stations, and hydrologic/meteorologic factors indicated that rain on active snowmelt-producing ground and areas of saturated ground recently covered by snow would be responsible for the 10-, 25-, and 100-year recurrence floods for Silver Bow Creek. USGS records for stations in the Clark Fork River Basin draining areas from 1,500 to 10,700 square miles showed maximum flood events occurring in May and June for 11 out of 13 cases.

AVAILABLE METEOROLOGICAL AND HYDROLOGICAL DATA

All readily available information from various federal, State of Montana, local, and private agencies was collected and reviewed to gain knowledge of the hydrological history of the Butte and Silver Bow Creek area. A complete list of agencies and data collected is contained in the Bibliography and includes information from the United States Geological Survey (USGS); State of Montana Department of Water Resources; United States Soil Conservation Service (SCS); Federal Emergency

Management Agency (FEMA); National Oceanic and Atmospheric Administration (NOAA); United States Bureau of Reclamation (USBR); United States Department of Commerce; United States Army Corps of Engineers, Hydrologic Engineering Center (HEC); City of Butte; Montana Department of Public Works; and local newspaper accounts of flooding dating back to 1892.

Weather stations from which precipitation records and other records were used for analyzing historic flood-producing storms are shown in Tables 6 and 7.

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Table 6
CLIMATOLOGICAL DATA

Location/Gage	Elevation	Basin	Data Type	Time of Observation (Hours)
Anaconda	5280	Silver Bow	Daily Precipitation/Temperatures	1700
Austin 1W	5000	Missouri	Daily Precipitation/Temperatures	1800
Boulder State School	4904	Big Hole	Hourly Precipitation/Daily Temperatures	1600
Butte FAA Airport	5540	Silver Bow	Hourly Weather Observations	
Butte 8S	6000	Silver Bow	Hourly Precipitation	
Deer Lodge 3W	4850	Clark Fork	Daily Precipitation/Temperatures	0800
Divide 2NW	5406	Big Hole	Hourly Precipitation/Daily Temperatures	2000
Drummond Aviation	3943	Clark Fork	Hourly Precipitation/Daily Temperatures	1700
East Anaconda	5200	Silver Bow	Daily Precipitation/Temperatures	0800
Helena WSO AP	3843	Missouri	Hourly Weather Observations/ Precipitation	N/A
Lincoln RS	4540	Missouri	Hourly Precipitation/Daily Temperatures	1600
Moulton Reservoir	6700	Silver Bow	Daily Precipitation/Temperatures	0800
Philipsburg RS	5207	Clark Fork	Hourly Precipitation/Daily Temperatures	1100

Table 6 (Continued)
CLIMATOLOGICAL DATA

Location/Gage	Elevation	Basin	Data Type	Time of Observation (Hours)
Philipsburg 7S	5708	Clark Fork	Daily Precipiation	1400
Rimini 4NE	4700	Missouri	Hourly Precipitation/Daily Temperatures	1700
Wise River 3WNW	5730	Big Hole	Daily Precipitation	1800

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Table 7
SNOW COURSE DATA

Location	Elevation	Basin	Data Type
Butte FAA Airport	5540	Silver Bow Creek	Daily snowfall/Snow on ground
Deer Lodge 3W	4850	Clark Fork	Daily snowfall/Snow on ground
Divide 2NW	5406	Big Hole River	Daily snowfall/Snow on ground
Drummond Aviation	3943	Clark Fork	Daily snowfall/Snow on ground
Barker Lakes	7500	Mill Creek	Daily water content of snow
Warm Springs	8000	Warm Springs Creek	Daily water content of snow
Black Mountain	7750	Cottonwood Creek	Monthly snow survey
Bull Mountain	6600	German Gulch	Monthly snow survey
Copper Mountain	7700	Boulder River	Monthly snow survey
Cottonwood Creek	6400	Cottonwood Creek	Monthly snow survey
Fred Burr Pass	8000	Warm Springs Creek	Monthly snow survey
Moulton Reservoir	6850	Silver Bow Creek	Monthly snow survey

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FLOODS SELECTED FOR ANALYSIS

Examination of available data indicated that flood events suitable for detailed hydrologic model analysis were recorded in January 1974, June 1975, May 1981, and February 1986. For these events, reconstruction of historical storms and flood hydrographs produced reliable estimates of basin runoff conditions and parameters for major floods.

For precipitation/runoff simulation, the U.S. Army Corps of Engineers (USCE) computer program HEC-1 was used. The program is designed to simulate the surface runoff response of a river basin to precipitation/snowmelt. Physical data such as temperature, rainfall, snowpack, basin sizes/slopes, wind, infiltration data, etc., that describe the river basin are input to the program. HEC-1 will then compute the amount of runoff that will occur for a given set of input conditions. These input conditions for the selected floods used for calibration were taken from nearby hydrological and meteorological recording stations for the respective dates. All recorded data is shown on the data files created for input to the HEC-1 computer program. Floods of known magnitude are used to "calibrate" the physical parameters of the drainage basins so that runoff responses can be verified. The Silver Bow Creek basin was divided into 23 subbasins with hydrographs being either calculated or combined at 46 locations within the basin.

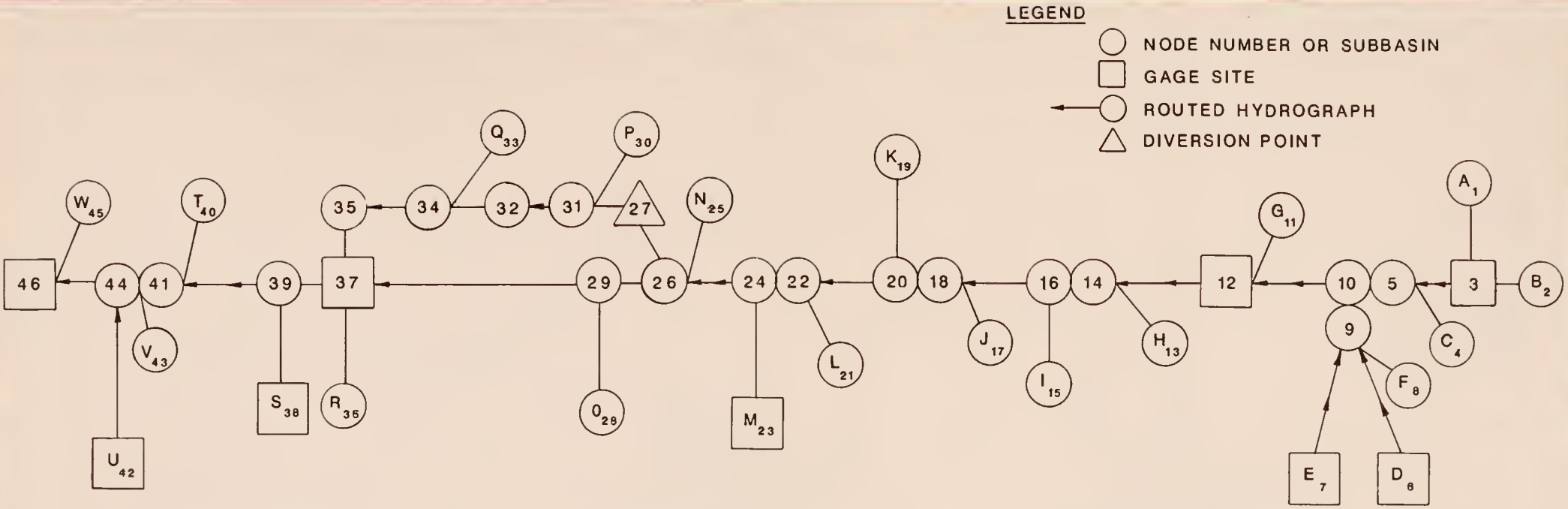
The HEC-1 hydrograph calculations, combining and routing locations, are shown on the schematic diagram (Figure 3) and the general subbasin map (Figure 4).

WINTER FLOODS: JANUARY 1974 AND FEBRUARY 1986

The January 1974 and February 1986 events had similar areas of frozen ground and snowmelt zones. The major difference between these events was that the February 1986 event had only very light rainshowers, while the January 1974 event had heavy rain in the Anaconda area.

ANTECEDENT CONDITIONS

Comparison of simulated to observed flow (where gage records were available) provided estimates of the effect of frozen or snow-covered ground on runoff generated by rain and snowmelt. Both the January 1974 and February 1986 flood events appeared to have similar conditions of high runoff from a low elevation area (4,000 to 5,500 feet). The proportion of area in this elevation zone is greater in the lower part of the Silver Bow Creek basin, especially in the Flint Creek and Mill/Willow Creeks subbasins, and subbasins local to the ponds. In the absence of frozen ground, these areas normally contribute little runoff since rain and snowmelt intensities are normally less than the infiltration rates of unfrozen soil. Infiltration or loss-rate coefficients used in the HEC-1 computer program for the areas of frozen ground were computed using



NODE NUMBER AND DESCRIPTION	SUBBASIN
1 SILVER BOW CREEK HEADWATERS (BERKELEY PIT)	A
2 EAST BUTTE LOCAL	B
3 SILVER BOW CREEK GAGE 12323170	
4 CENTRAL BUTTE LOCAL	C
5 SILVERBOW CREEK ABOVE BLACKTAIL CREEK	
6 BLACKTAIL CREEK GAGE 12323200	D
7 BASIN CREEK GAGE 12323220	E
8 LOWER BLACKTAIL LOCAL	F
9 BLACKTAIL CREEK AT MOUTH	
10 SILVER BOW CREEK BELOW BLACKTAIL CREEK	
11 WEST BUTTE LOCAL	G
12 SILVER BOW CREEK GAGE 12323250	
13 CANADA CREEK LOCAL	H
14 SILVER BOW CREEK ABOVE SAND CREEK	
15 SAND CREEK	I
16 SILVER BOW CREEK BELOW SAND CREEK	

NODE NUMBER AND DESCRIPTION	SUBBASIN
17 RAMSAY LOCAL	J
18 SILVER BOW CREEK ABOVE BROWNS GULCH	
19 BROWNS GULCH	K
20 SILVER BOW CREEK BELOW BROWNS GULCH	
21 MCCLEERY GULCH LOCAL	L
22 SILVER BOW CREEK ABOVE GERMAN GULCH	
23 GERMAN GULCH GAGE 12323500	M
24 SILVER BOW CREEK BELOW GERMAN GULCH	
25 FLINT CREEK LOCAL	N
26 SILVER BOW CREEK ABOVE PONDS DIVERSION	
27 PONDS DIVERSION	
28 MILL AND WILLOW CREEKS	O
29 SILVER BOW CREEK BELOW MILL/WILLOW CREEKS	
30 POND 3 LOCAL	P

NODE NUMBER AND DESCRIPTION	SUBBASIN
31 POND 3 INFLOW	
32 POND 3 OUTFLOW	
33 POND 2 LOCAL	Q
34 POND 2 INFLOW	
35 POND 2 OUTFLOW	
36 COOK CREEK LOCAL	R
37 SILVER BOW CREEK GAGE 12323750	
38 WARM SPRINGS CREEK GAGE 12323770	S
39 CLARK FORK RIVER BELOW WARM SPRINGS CREEK	
40 LOST CREEK LOCAL	T
41 CLARK FORK RIVER ABOVE RACETRACK CREEK	
42 RACETRACK CREEK GAGE 12324100	U
43 RACETRACK CREEK LOCAL	V
44 CLARK FORK RIVER BELOW RACETRACK CREEK	
45 PETERSON CREEK LOCAL	W
46 CLARK FORK RIVER AT DEER LODGE GAGE 12324200	

Figure 3
HYDROGRAPH ROUTING AND COMBINING SCHEMATIC
SILVER BOW CREEK FLOOD MODELING STUDY

Figure 4
GENERAL SUBBASIN MAP
SILVER BOW CREEK FLOOD MODELING STUDY

an exponential loss-rate equation. This results in the actual precipitation being lost to infiltration to vary over the entire storm period.

Areas of frozen ground with low infiltration were estimated during the HEC-1 model calibration. Snow depth and water content by 1,000-foot elevation zones were determined from daily weather observations at Butte FAA Airport, Deer Lodge, Moulton Reservoir, and Warm Springs; and February 1 and March 1 snow survey data. Antecedent snow cover depths were used to determine initial losses for the runoff simulations.

PRECIPITATION

The first step in the reconstitution of the flood events was determination of basin precipitation. Precipitation data were limited to hourly surface weather observations at Butte (hourly precipitation was not recorded), 6-hourly precipitation at Butte; and daily precipitation at Anaconda, East Anaconda, Moulton Reservoir, the Warm Springs snow pillow, and the Barker Lakes snow pillow.

During the January 1974 event the light snowfall at Butte that began the morning of January 14 changed to rain by 4:00 p.m. The Butte area then received very light rain showers until 5:00 p.m. on January 15. Precipitation records indicated a total rainfall for this period of 0.07 inch at Butte and the highest hourly recorded rain was 0.01 inch. However, during the same time period East Anaconda received 1.60 inches of rain which

led to severe flooding on Mill, Willow, and Warm Springs Creeks. Hourly rainfall amounts used in the HEC-1 program were distributed evenly for these subbasins from 10:00 a.m. on January 14 to 5:00 p.m. on January 15. Flows recorded at the Silver Bow Creek gage below the ponds indicated that most of the runoff generated came from the Mill and Willow Creek watersheds. Smith Gulch flows in the Sand Creek subbasin indicated that heavy rainfall probably did not occur in the upper Silver Bow Creek basin, and runoff in the upper basin came from snowmelt only.

For the February 23 to 25, 1986 event, a series of storm systems in a strong southwest flow of air originating near the Hawaiian Islands caused heavy rain and widespread flooding across California, Nevada, and Idaho. No significant precipitation occurred in the Silver Bow Creek basin, but high winds and warm air temperatures caused rapid snowmelt and localized flood runoff from frozen ground. The only recorded precipitation, after the snowfall on the morning of February 23, was 0.02 to 0.05 inch in the Anaconda/Deer Lodge area during the evening of February 23.

SNOWMELT

Snow cover at lower elevations completely melted during both the 1974 and 1986 events. Hourly surface weather observations at Butte Airport including air temperature, dewpoint temperature, wind speed, air pressure, and cloud cover were used in a surface energy budget equation within computer program HEC-1 to

compute snowmelt. Maximum/minimum daily air temperatures at Anaconda and Deer Lodge were used to estimate changes in air temperature between Butte and the lower Silver Bow Creek basin. These temperatures showed that air temperature decreased approximately 2°F for each 1,000-foot increase in elevation. This decrease in air temperature was used for the entire elevation range of each subbasin.

BASIN HYDROGRAPHS

Synthetic unit hydrographs were determined for each subbasin using Snyder's coefficients which are lag time and peaking coefficients. Except for Warm Springs Creek no observed hydrographs were available for any of the subbasins, so lag time was computed from an empirical formula using the contributing area of low-elevation frozen ground. It was found that the lag times for each subbasin during winter and spring floods were about the same. This is possibly due to the delaying or retardation effect in winter from existing snow-covered ground on the lower elevations as compared to the relative quick response of runoff from the higher saturated snowpack areas during spring storms.

The peaking coefficient was selected to be consistent with surface runoff retardation due to snow cover and the slope of the low elevation runoff zones.

FLOOD CHANNEL ROUTING

Flood hydrograph routing was accomplished using the Muskingum method. This method used routing parameters of a travel time coefficient and an attenuation coefficient. Travel times were determined from velocities obtained from the HEC-2 backwater calculations. The attenuation coefficient was set at a value consistent with the relatively low attenuation of flood hydrographs staying mainly in the channel.

FLOOD POND ROUTING

Flood routing through Pond 3 and Pond 2 was done using flow-diversion relationships at the diversion works, and flow-storage-discharge relationships for Pond 3 and Pond 2. In both events additional flow was released from the ponds by manual adjustments of the ponds' control structures due to fear of overtopping pond dikes. The temporary berm blocking the bypass channel below the diversion works was removed or failed during peak flow. Flow regulation by pond operations attenuated the flood hydrographs and added additional water at the USGS Silver Bow Creek gage downstream of the ponds. For the winter floods this water (added into the stream system) was not input into the HEC-1 model which resulted in the computed hydrographs being less or below the observed hydrographs beginning near the recession limb of the hydrograph.

HEC-1 CALIBRATION

The model calibration process consisted of adjusting the area of nearly impervious frozen ground. These adjustments were based on climatological data which included SCS snow course records, temperature records for the area, and elevation. Except for a limited impervious area representing pavement in Butte and water surface areas, the frozen ground areas were restricted to a portion of the 4,000- to 5,500-foot elevation zones which were adjusted for the best reconstruction of recorded flow. Due to ice and station failure, a recorded hydrograph was not available for Silver Bow Creek below the ponds for the January 1974 event. The USGS estimated this hydrograph from the recorded hydrograph for Clark Fork at Drummond and high water marks. A peak flow measurement was available for Smith Gulch.

More observed flow data were available for the February 1986 event. Recorded hydrographs were available for Silver Bow Creek in East Butte, Silver Bow Creek below Blacktail Creek, and Clark Fork at Deer Lodge. The calibration process for this event was the same as that used for the 1974 flood. The input rainfall, temperatures, wind, and dew point were taken from actual records for each period. The 1974 contributing areas to runoff were found to be different from the 1986 areas as the flow and related hydrological values varied.

Results of the calibrations for the 1974 and 1986 events are shown on Figures 5 through 8.

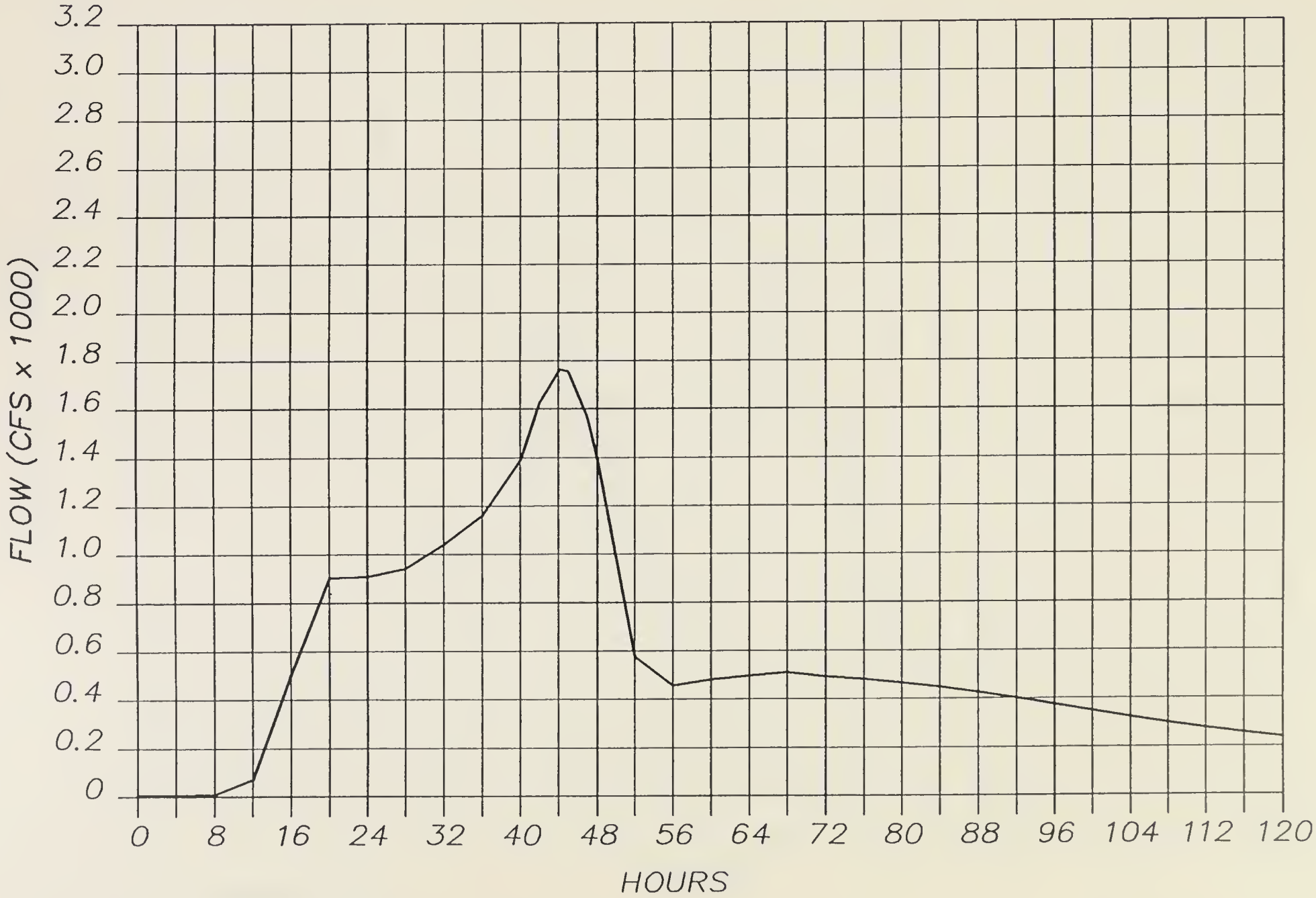


Figure 5
JANUARY 14 TO 18, 1974 CALIBRATION; NODE 37; SILVER BOW CREEK GAGE ABOVE WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

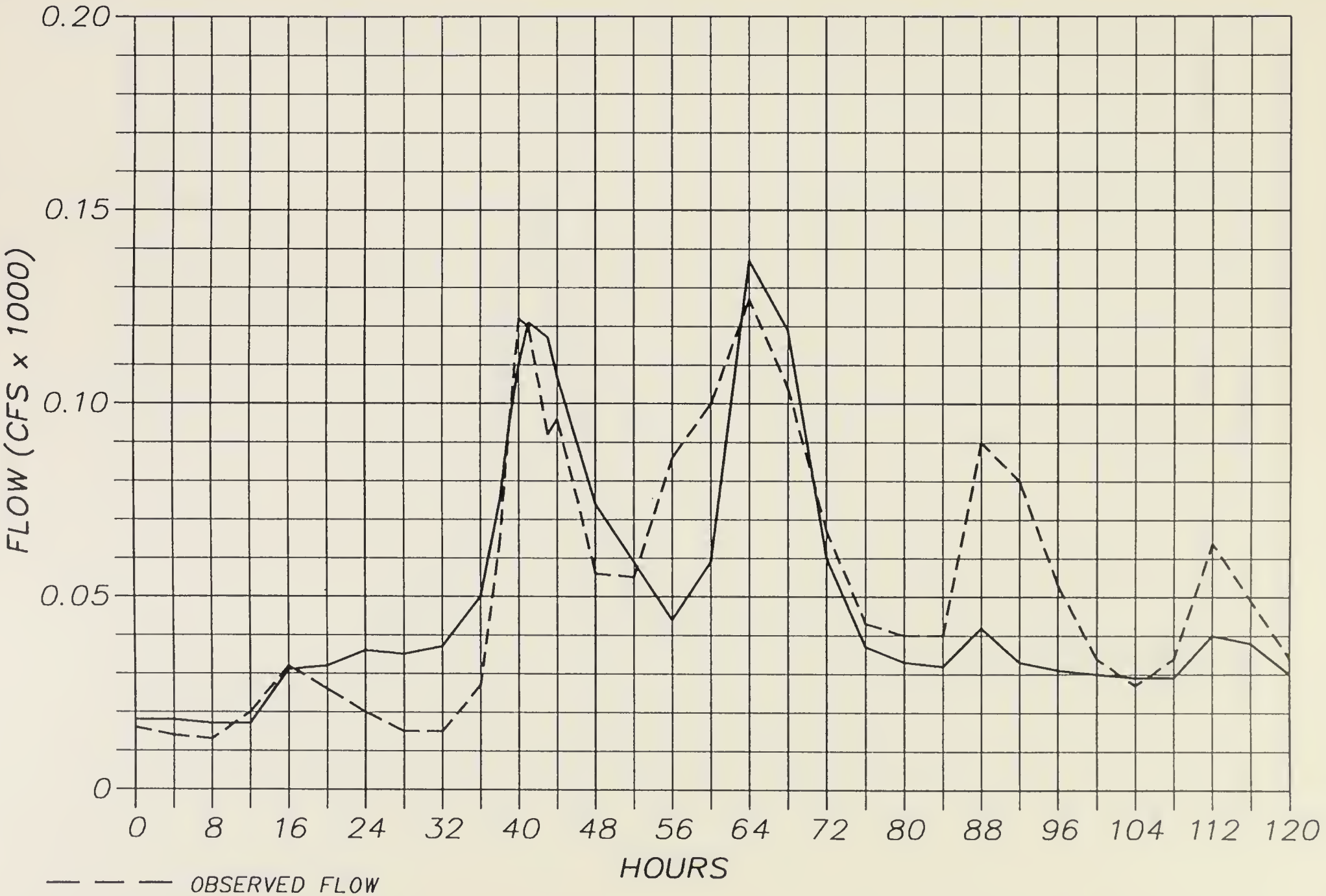


Figure 6
FEBRUARY 24 TO 27, 1986 CALIBRATION; NODE 12; SILVER BOW CREEK GAGE BELOW BLACKTAIL CREEK

SILVER BOW CREEK FLOOD MODELING STUDY

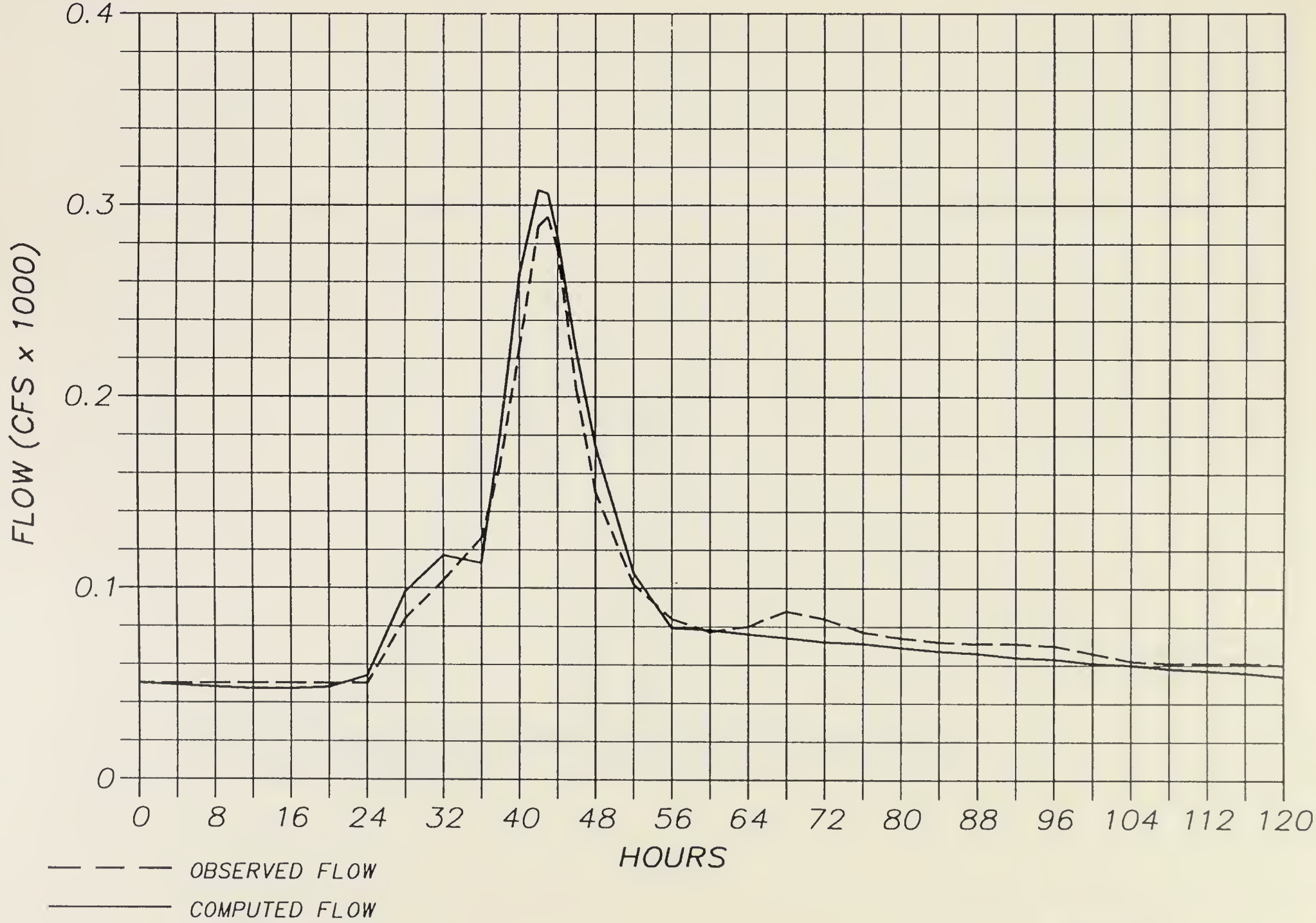


Figure 7
FEBRUARY 23 TO 27, 1986 CALIBRATION; NODE 38;
WARM SPRINGS CREEK AT WARM SPRINGS
SILVER BOW CREEK FLOOD MODELING STUDY

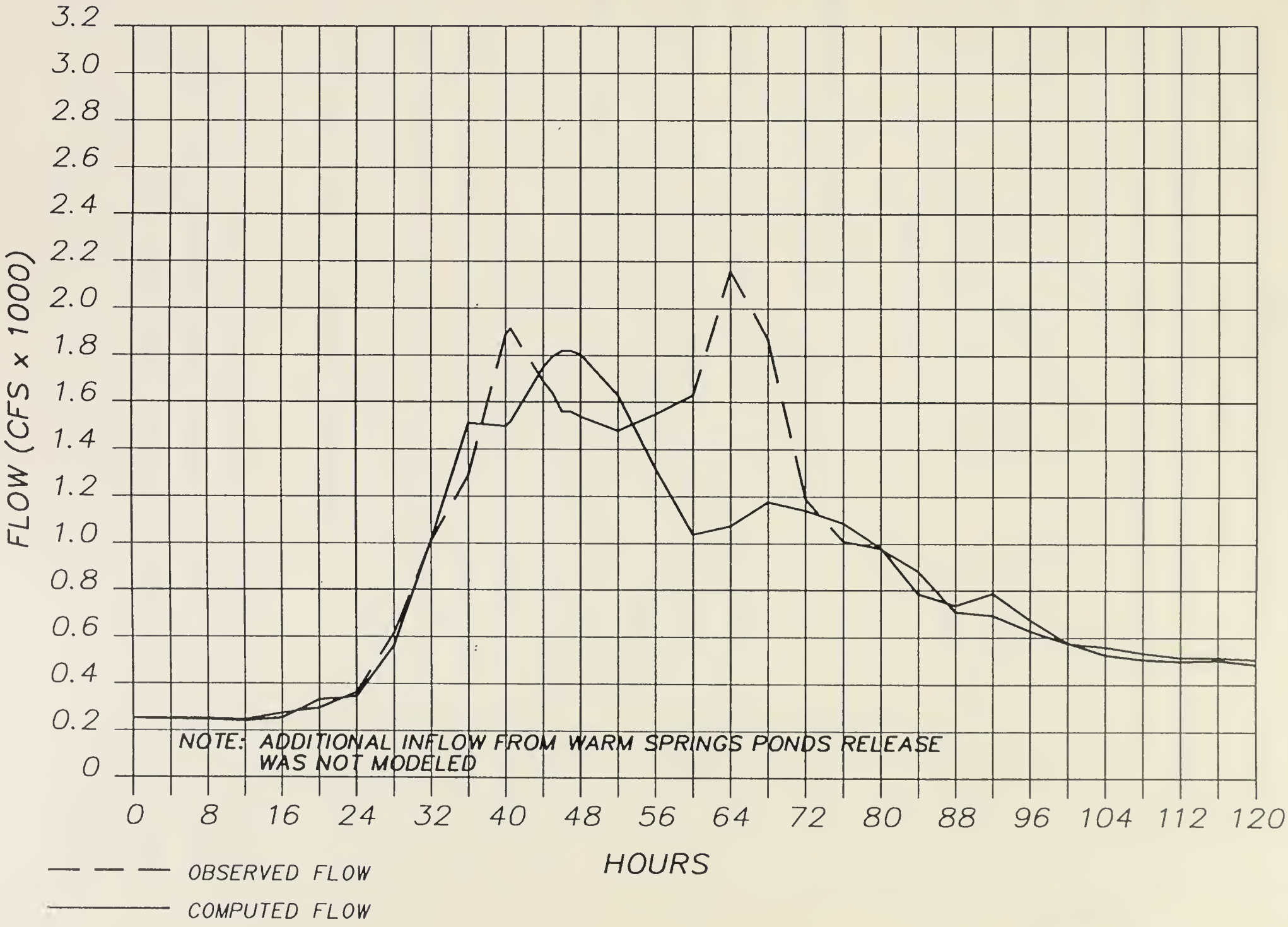


Figure 8
FEBRUARY 23 TO 27, 1986 CALIBRATION; NODE 46;
CLARK FORK GAGE AT DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

SPRING SNOWMELT/RAIN FLOODS: JUNE 1975 AND MAY 1981

For spring snowmelt/rain floods, the June 1975 and May 1981 events were used to calibrate the HEC-1 runoff model. Both of these events had similar characteristics of precipitation and snowmelt runoff from high-elevation contributing areas. The June 1975 event had greater rainfall in the upper Silver Bow Creek basin, while the May 1981 event had greater rainfall on the northern border of the basin.

ANTECEDENT CONDITIONS

Effective runoff contributing areas for these events were limited to the active snowmelt areas and ground recently saturated from snowmelt. These areas encompassed most of the basin above 7,000 feet and a portion of the 6,000- to 7,000-foot zone. Runoff contributing areas below 6,000 feet were limited to impervious areas of pavement and the water surfaces of streams and ponds. The infiltration rates of the active snowmelt zones were very low due to the shallow saturated soils. There were no initial losses since the snowpack and soil were already saturated.

Snow depth and water content by elevation zone were estimated from snow survey measurements made on May 1 and June 1, 1975. On June 17, 1975, snow cover was very limited on north slopes below 7,000 feet but was continuous except for south slopes above the 7,000-foot elevation. On May 20, 1981, snow cover

was more extensive and deeper than in June 1975, especially above 8,000 feet. However, snow cover below 7,000 feet was limited to a few shaded north slopes. The actual runoff contributing areas of snow-covered ground were modified as part of the calibration process.

PRECIPITATION

The most important part of the reconstitution of these flood events was determination of basin precipitation. Precipitation data were available for low elevation stations, but no data existed for the upper elevations where the runoff was originating. Precipitation was assumed to increase with elevation similar to the increase with elevation shown on the basin topographic map (Figure 9) and the mean annual precipitation map (Figure 2).

In June 1975 hourly precipitation data were available for Butte 8S and hourly weather observations were available for Butte Airport. Daily precipitation and maximum/minimum air temperatures were available at Butte Airport, East Anaconda, and Deer Lodge. The storm event on June 17-20, 1975, affected most streams on the Continental Divide in western Montana (Ref. 6). Rainfall began at midday on June 17 and continued until late evening on June 19. Peak intensity rainfall and resulting flooding occurred from 7:00 a.m. to 6:00 p.m. on June 19. Flood peaks in the Silver Bow Creek basin for this event had recurrence intervals of 10 to 20 years.

Figure 9
TOPOGRAPHIC MAP
SILVER BOW CREEK FLOOD MODELING STUDY

The storm causing the May 1981 flood developed off the coast of Oregon on May 18. It established a closed upper level atmospheric low circulation in Nevada by May 20. A ridge of high pressure to the east stalled movement of the storm, causing it to move slowly to the northeast across southern Idaho and northern Wyoming. Clockwise circulation around the storm transported moisture from the Gulf of Mexico to the Continental Divide of western Montana.

In the early morning of May 22, 1981, heavy precipitation was concentrated over an area just north of the Silver Bow Creek basin. Boulder River to the northeast of Butte, Cottonwood Creek near Deer Lodge, and streams along the Continental Divide west of Helena all experienced record flood peaks having recurrence intervals at or greater than 100 years (Ref. 7). In the upper Silver Bow Creek basin flood peaks were generally slightly lower than those observed in June 1975. The largest flood peaks were on subbasins downstream of German Gulch, with maximum rainfall and runoff on Cottonwood Creek near Deer Lodge.

In the Silver Bow Creek basin, hourly weather observations were available for Butte Airport. Daily rainfall observations were available at Butte Airport, East Anaconda, and Deer Lodge. An analysis of total storm precipitation for these stations and others surrounding the Silver Bow Creek basin showed that the heaviest rainfall occurred near the Continental Divide north of Butte. Hourly rainfall for input to the HEC-1 program was estimated from the Butte Airport weather observations and daily

rainfall totals at Butte and East Anaconda. A period of thundershowers occurred during the afternoon and evening of May 20. Nearly continuous rain fell from 7:00 a.m. on May 21 to 9:00 a.m. on May 22. The rainfall that caused the flood peaks occurred during a few hours near midnight on May 21.

SNOWMELT

Snow cover at high elevations rapidly melted in response to warm air temperatures, wind, and rainfall. Hourly surface weather observations of air temperature, dew point temperature, wind speed, cloud cover, and air pressure at Butte Airport were used in the HEC-1 program's surface energy budget equations to compute snowmelt. Adjustments in temperature and wind speed were made to account for differences between Butte Airport and the snow zones above 7,000 feet.

BASIN HYDROGRAPHS

Synthetic unit hydrographs were determined for each subbasin using Snyder's coefficients. No observed hydrographs were available for any of the subbasins. Snyder's lag time and peaking factor were computed from empirical formulas using the contributing area and the slope and shape of the active snow-melt zones.

FLOOD CHANNEL ROUTING

Flood channel routing was done using the Muskingum method. Travel times were determined from velocities obtained from the HEC-2 backwater calculations. Attenuation factors were the same as those used for winter flood events.

FLOOD POND ROUTING

Flood routing through Pond 3 and Pond 2 was done using a flow-diversion relationship at the diversion works, and flow-storage-discharge relationships for Pond 3 and Pond 2. As in 1974 and 1986, additional water was released from the ponds by manual adjustments of outlet control structures to prevent overtopping the pond dikes. This water was added to the HEC-1 model. Also, the temporary dike at the diversion into Pond 3 either washed out or was removed to allow water to flow into the Mill/Willow Bypass.

HEC-1 CALIBRATION

The HEC-1 calibration process consisted of adjusting the area of active snowmelt (snow cover above 6,000 feet) and making minor changes to the timing of rainfall (especially in June 1975 when no basin records of hourly rainfall existed). These snowmelt contributing areas were estimated from SCS snow course stations for the period. The areas of the basin which are heavily covered with vegetation provide a long-lasting snow-

pack, and these areas were adjusted until calculated runoff matched the recorded data.

In June 1975 an observed flow hydrograph was available for Silver Bow Creek downstream of the ponds. Data on peak flows were available for German Gulch and Racetrack Creek. In May 1981 an observed flow hydrograph was available for Clark Fork at Deer Lodge and peak flow was available for Smith Gulch. Results of the calibrations for June 1975 and May 1981 are shown on Figures 10 through 17.

VERIFICATION

The June 4 to 6, 1908, flood event was used to verify the calibrated HEC-1 model. Detailed accounts of damage from flood flows in the Silver Bow Creek watershed between Butte and Anaconda and the general vicinity were recorded by the local newspapers of that time. The newspapers documented "Rivers on Rampages - Worst in History" accounts of flooded areas, railroad washouts, bridge damages, heavy rainfall and snowpack, and personal hardships because of flooding.

Available climatological data recorded for the time included daily rainfall and maximum/minimum temperatures at Butte and Anaconda. These data were input to the calibrated HEC-1 model so that calculations of flood flow for this storm could be made.

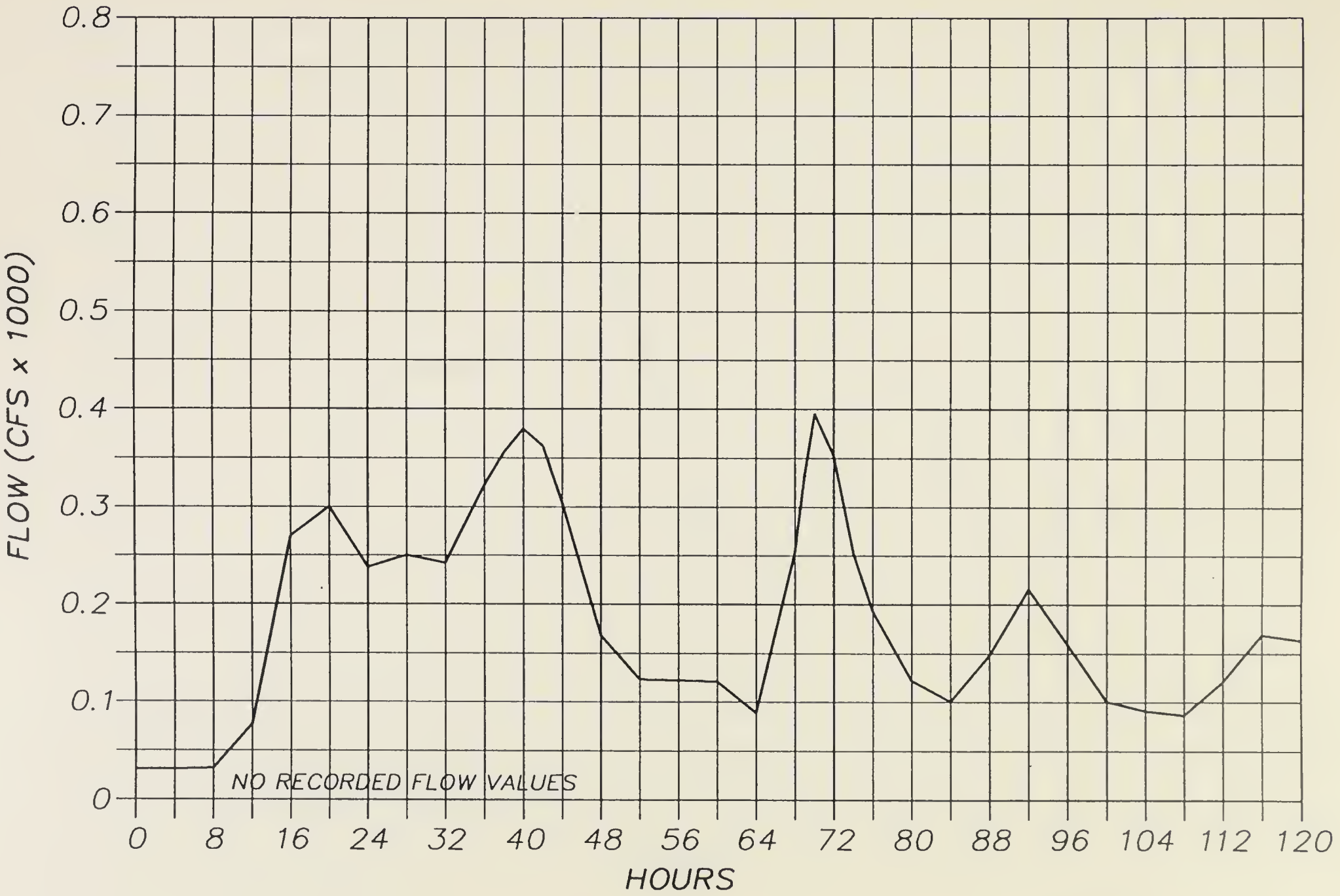


Figure 10
JUNE 17 TO 21, 1975 CALIBRATION; NODE 12;
SILVER BOW CREEK GAGE BELOW
BLACKTAIL CREEK

SILVER BOW CREEK FLOOD MODELING STUDY

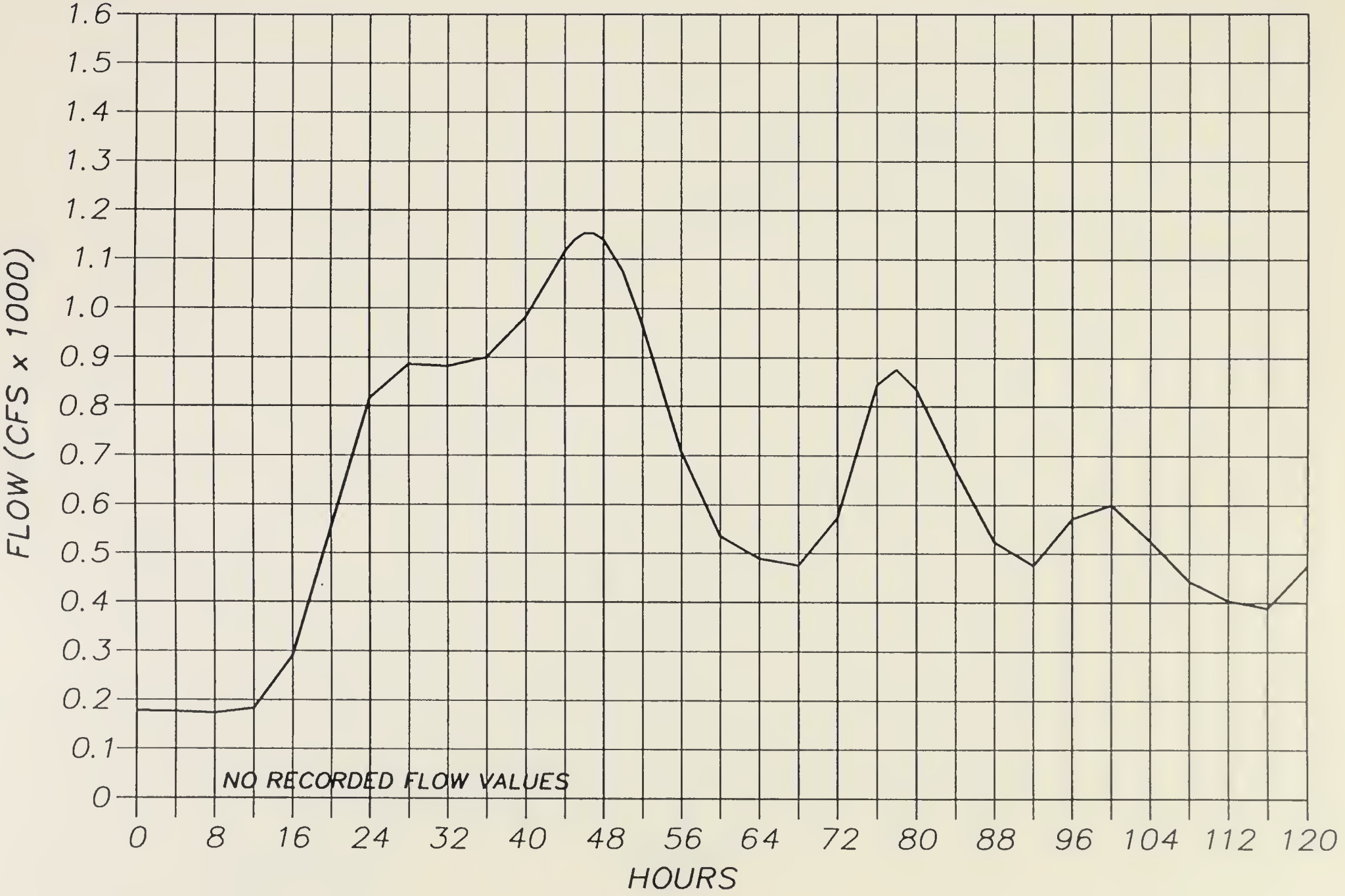


Figure 11
JUNE 17 TO 21, 1975 CALIBRATION; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

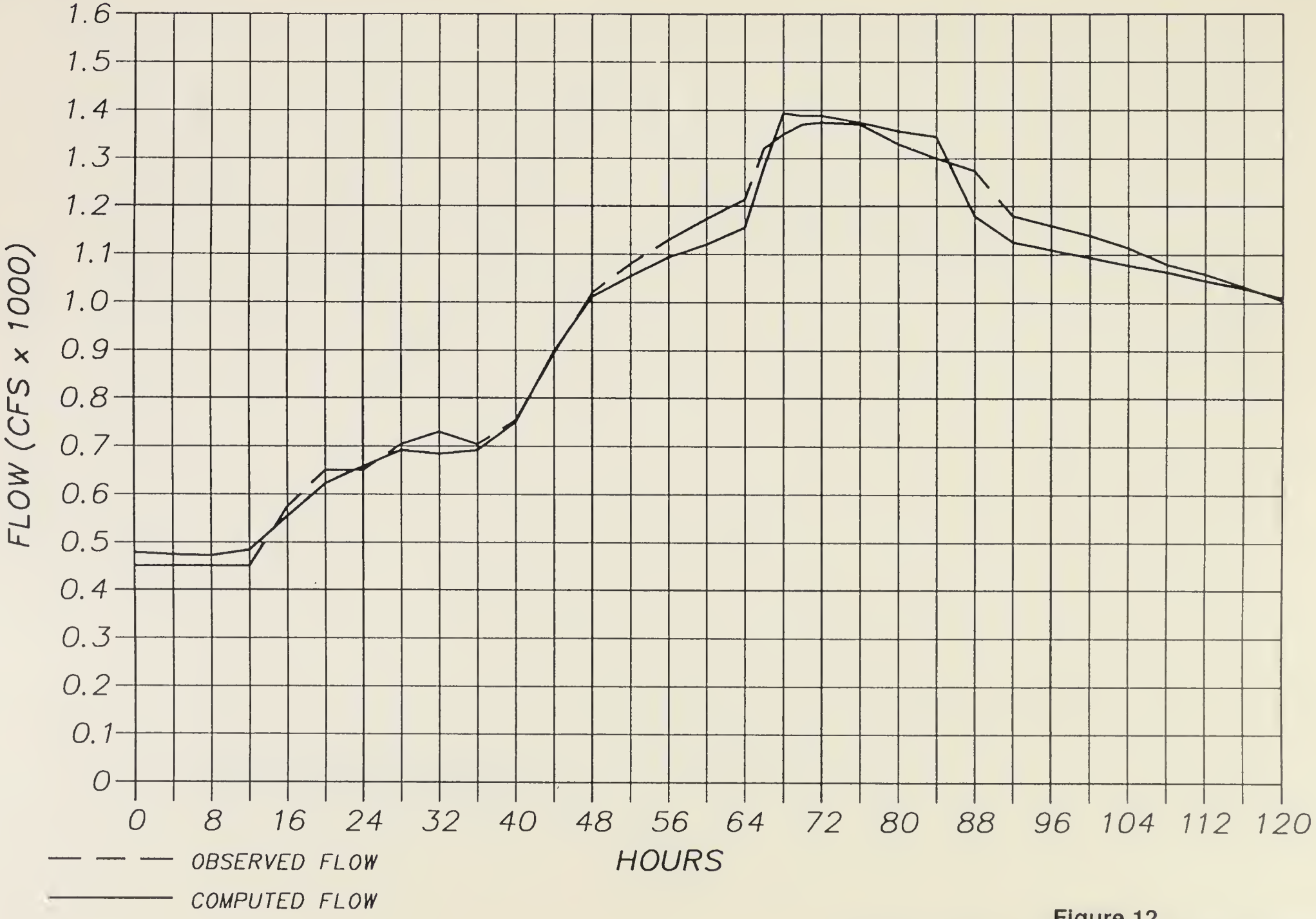


Figure 12
JUNE 17 TO 21, 1975 CALIBRATION; NODE 37;
SILVER BOW CREEK GAGE ABOVE
WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

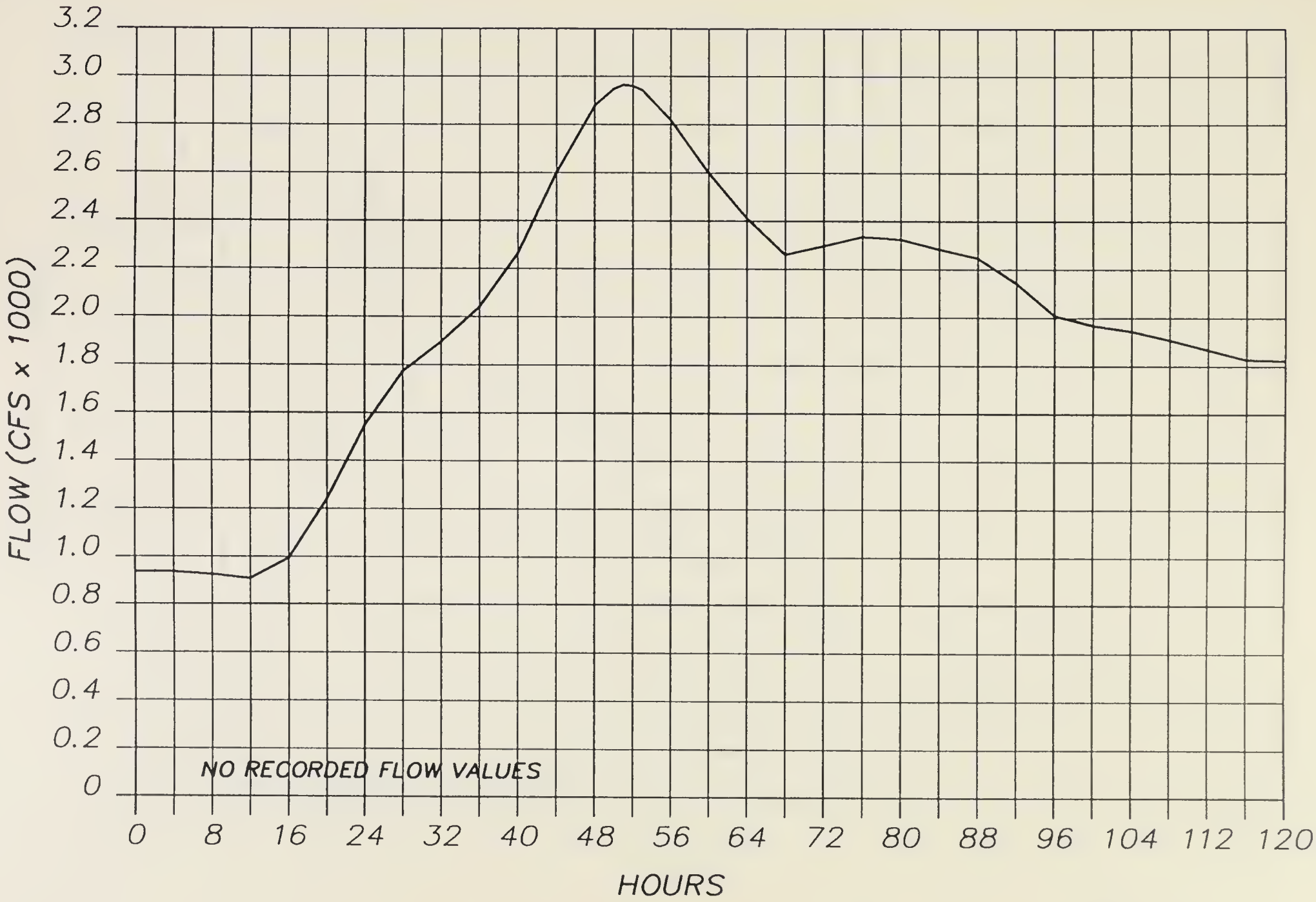


Figure 13
JUNE 17 TO 21, 1975 CALIBRATION; NODE 46;
CLARK FORK GAGE AT DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

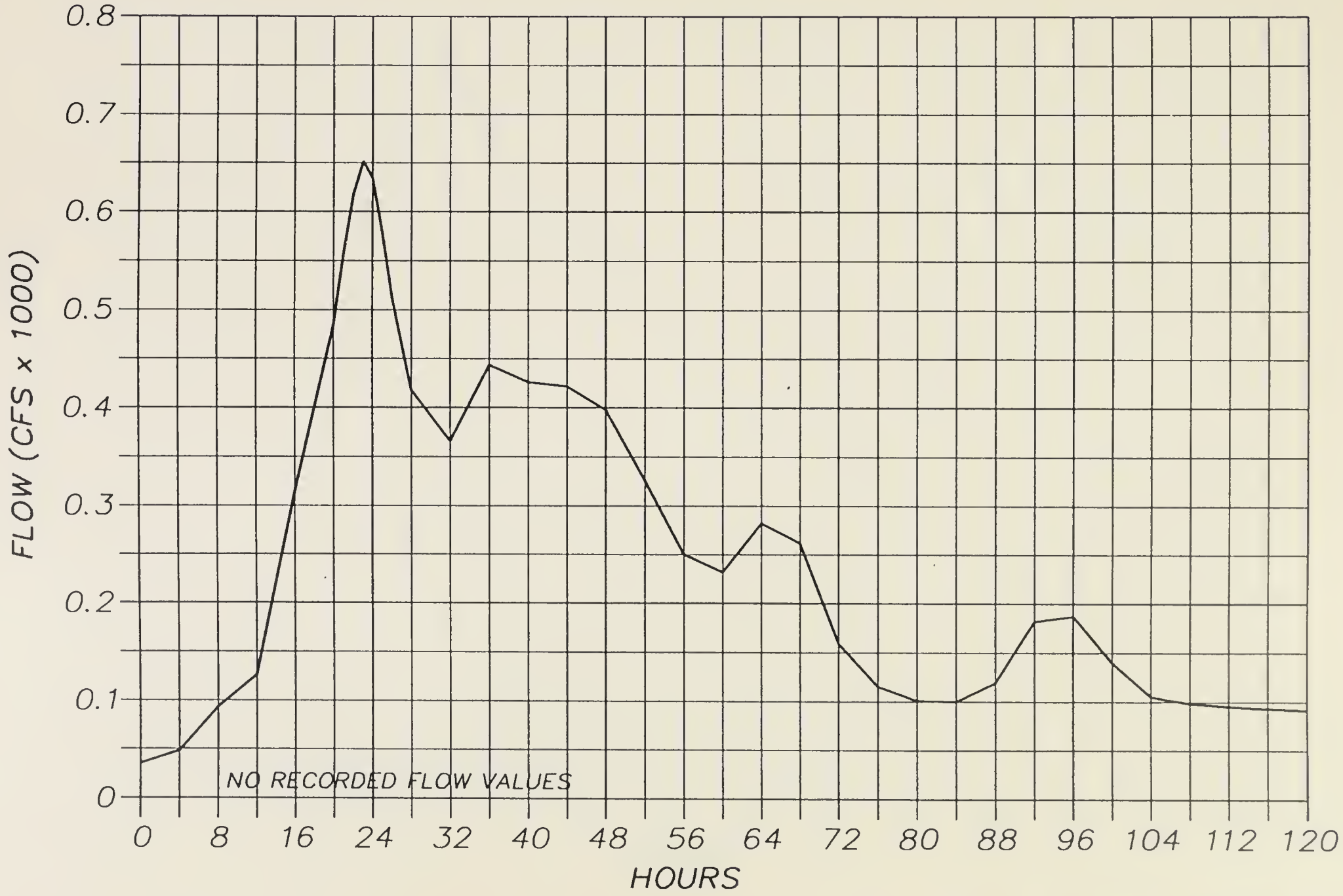


Figure 14
MAY 20 TO 24, 1981 CALIBRATION; NODE 12; SILVER BOW CREEK GAGE BELOW BLACKTAIL CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

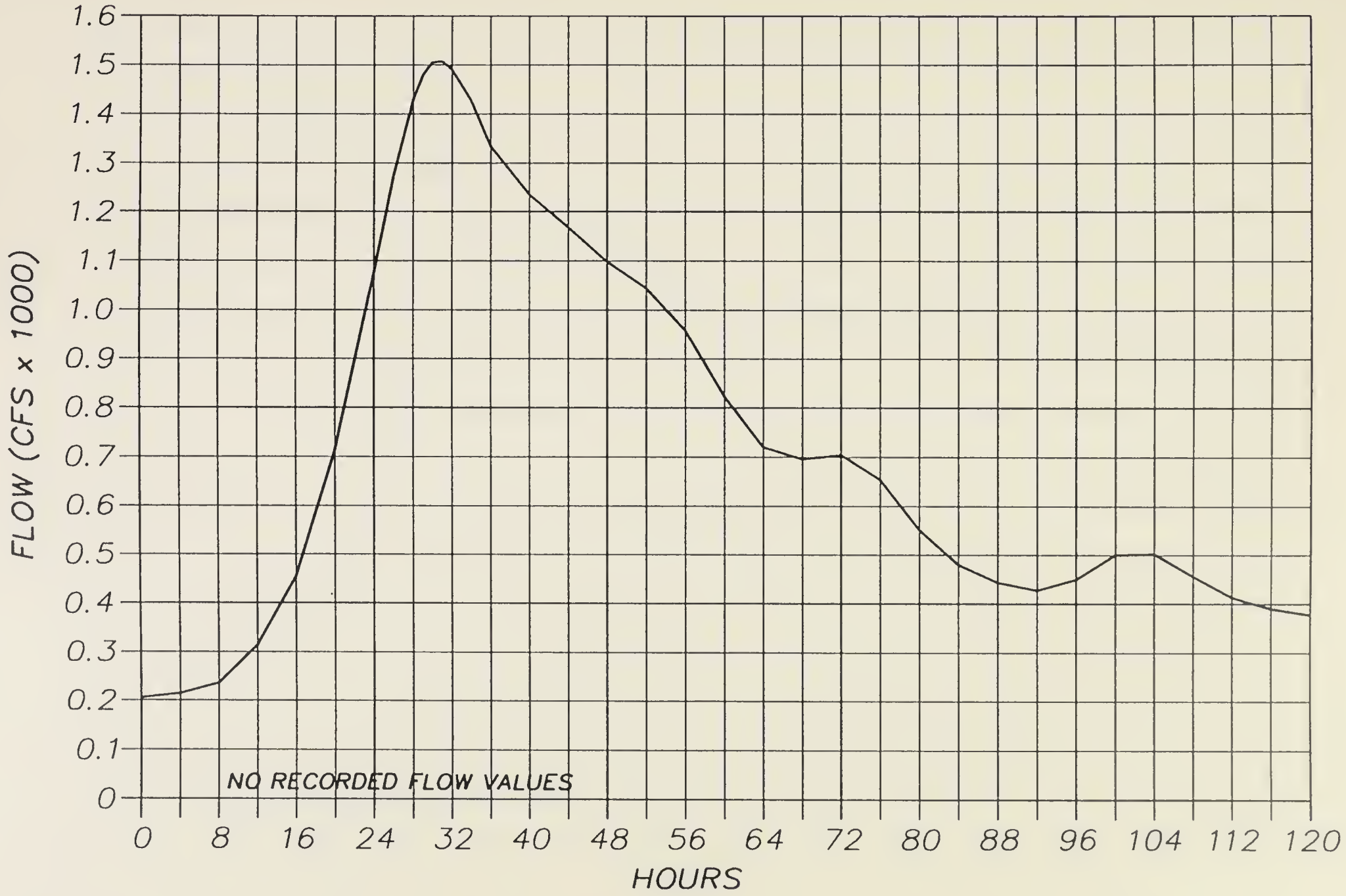


Figure 15
MAY 20 TO 24, 1981 CALIBRATION; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

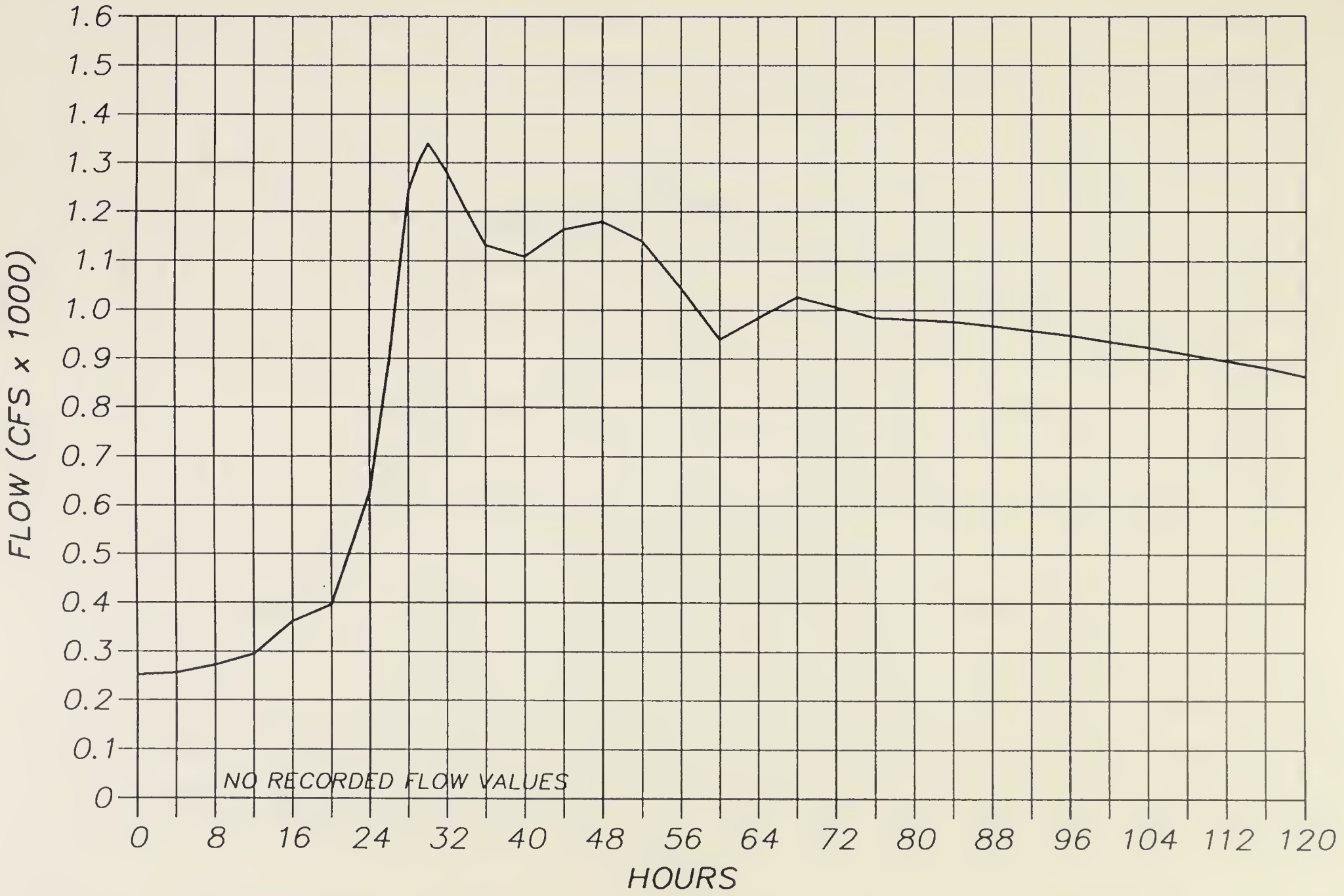


Figure 16
MAY 20 TO 24, 1981 CALIBRATION; NODE 37;
SILVER BOW CREEK GAGE ABOVE
WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

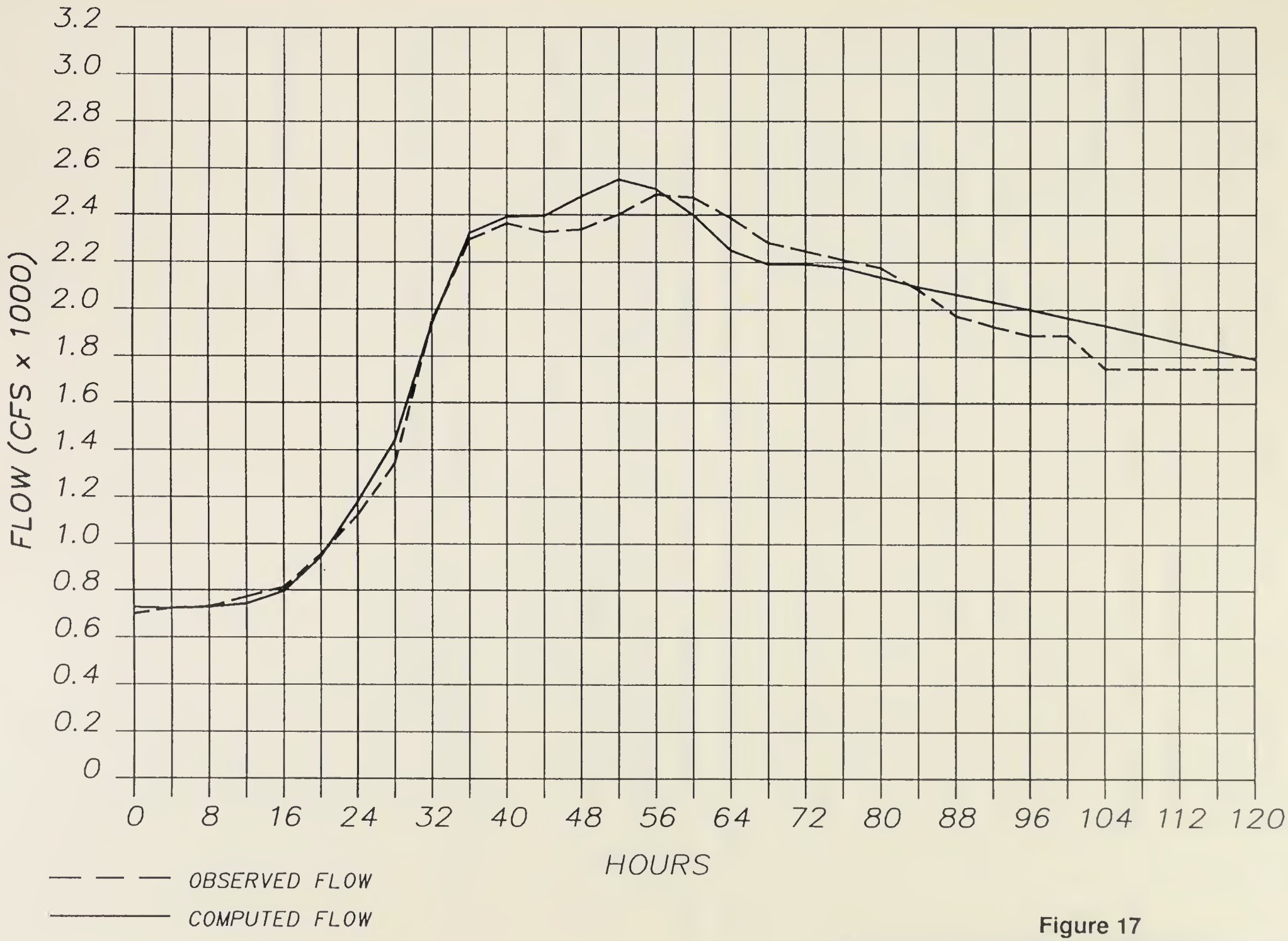


Figure 17
MAY 20 TO 24, 1981 CALIBRATION; NODE 46;
CLARK FORK GAGE AT DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

The daily rainfall was distributed hourly, consistent with the 1975, 1981, and synthetic NOAA storms. The maximum/minimum temperatures were comparable to those observed in May 1981. Based on the newspaper accounts of the record snowpack and accounts of snow cover in Butte for early June, active snowmelt zones producing runoff were input as those areas between 5,000 and 6,000 feet. Because of the water retention capacity of the recently fallen snow, runoff was limited in this elevation zone with no runoff generated during the peak flow period from areas above 6,000 feet. The amount of runoff as calculated by the HEC-1 program for this storm produced flood flows that would be consistent with the flows required during actual conditions to produce flood damages as recorded. The peak flow for Silver Bow Creek as calculated near Warm Springs, based on the flood flow frequency analysis as outlined in the following sections, would be approximately a 50-year recurrence interval flood. The flood peak for Clark Fork at Drummond for this storm was also consistent with this recurrence interval.

The results of the HEC-1 computed flood hydrographs for the 1908 flood are shown in Figures 18 through 22.

BOIT642/025.50/jms

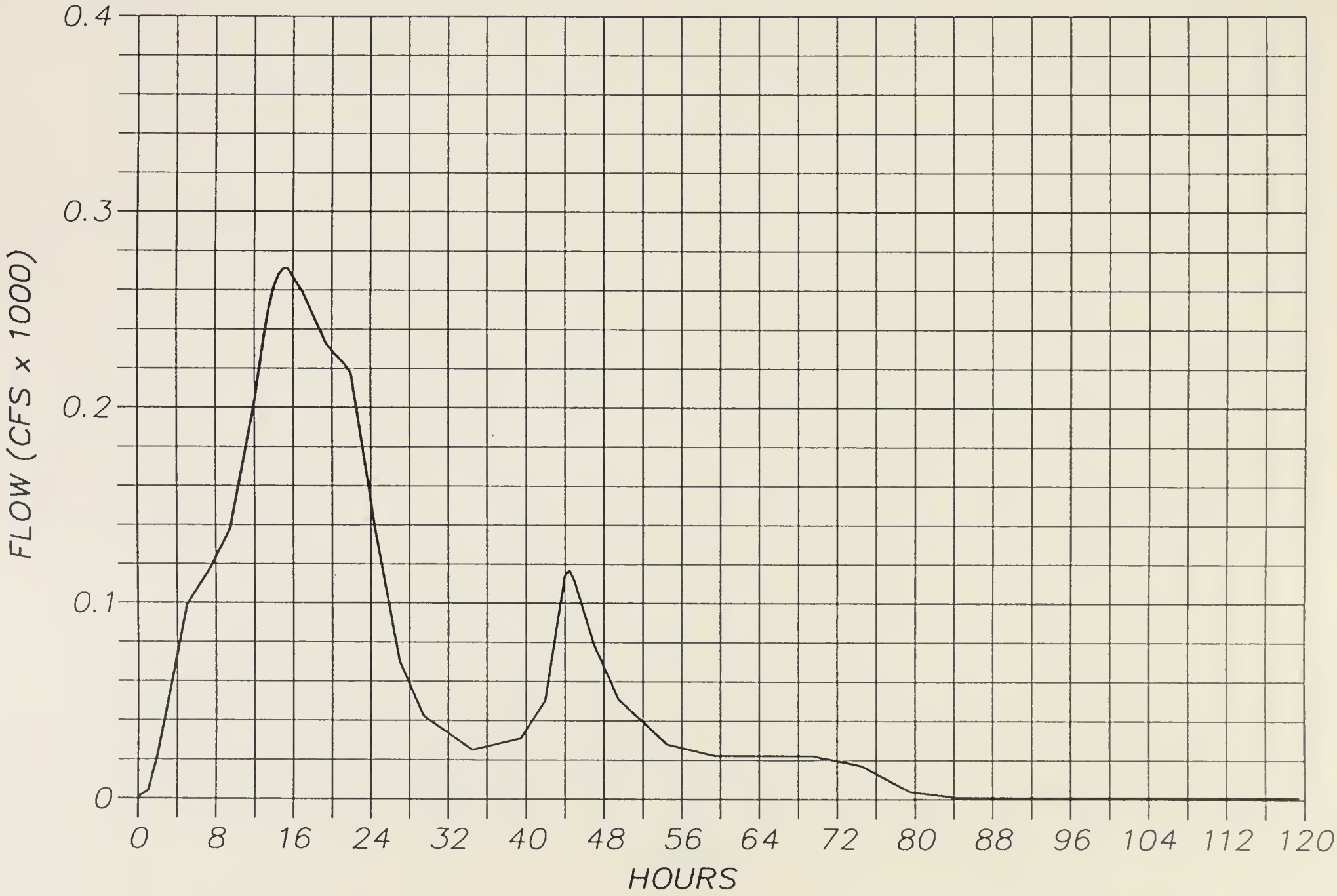


Figure 18
COMPUTED 1908 FLOOD; NODE 5;
SILVER BOW CREEK ABOVE BLACKTAIL CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

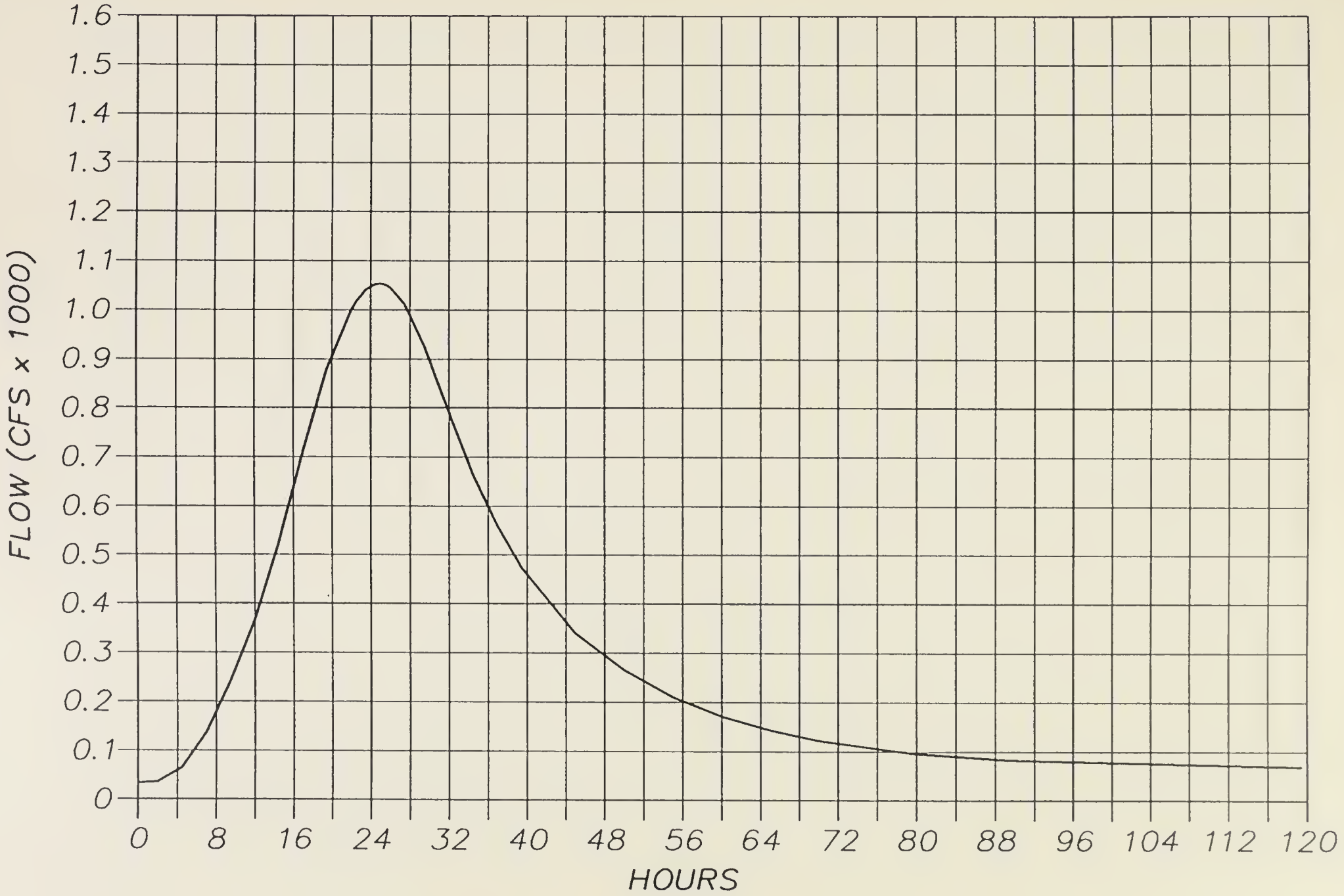


Figure 19
COMPUTED 1908 FLOOD; NODE 9;
BLACKTAIL CREEK AT MOUTH
SILVER BOW CREEK FLOOD MODELING STUDY

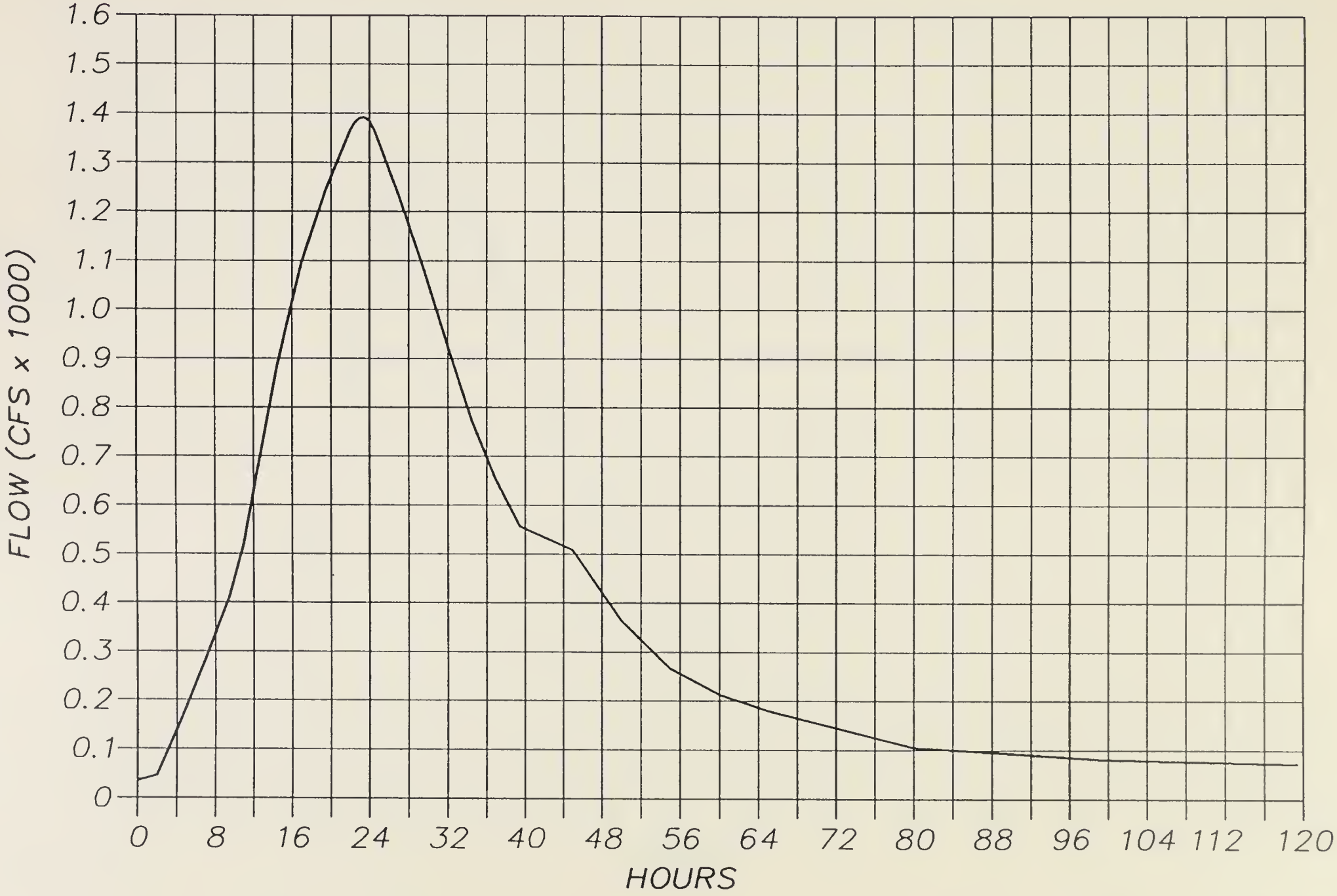


Figure 20
COMPUTED 1908 FLOOD; NODE 12;
SILVER BOW CREEK BELOW BLACKTAIL CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

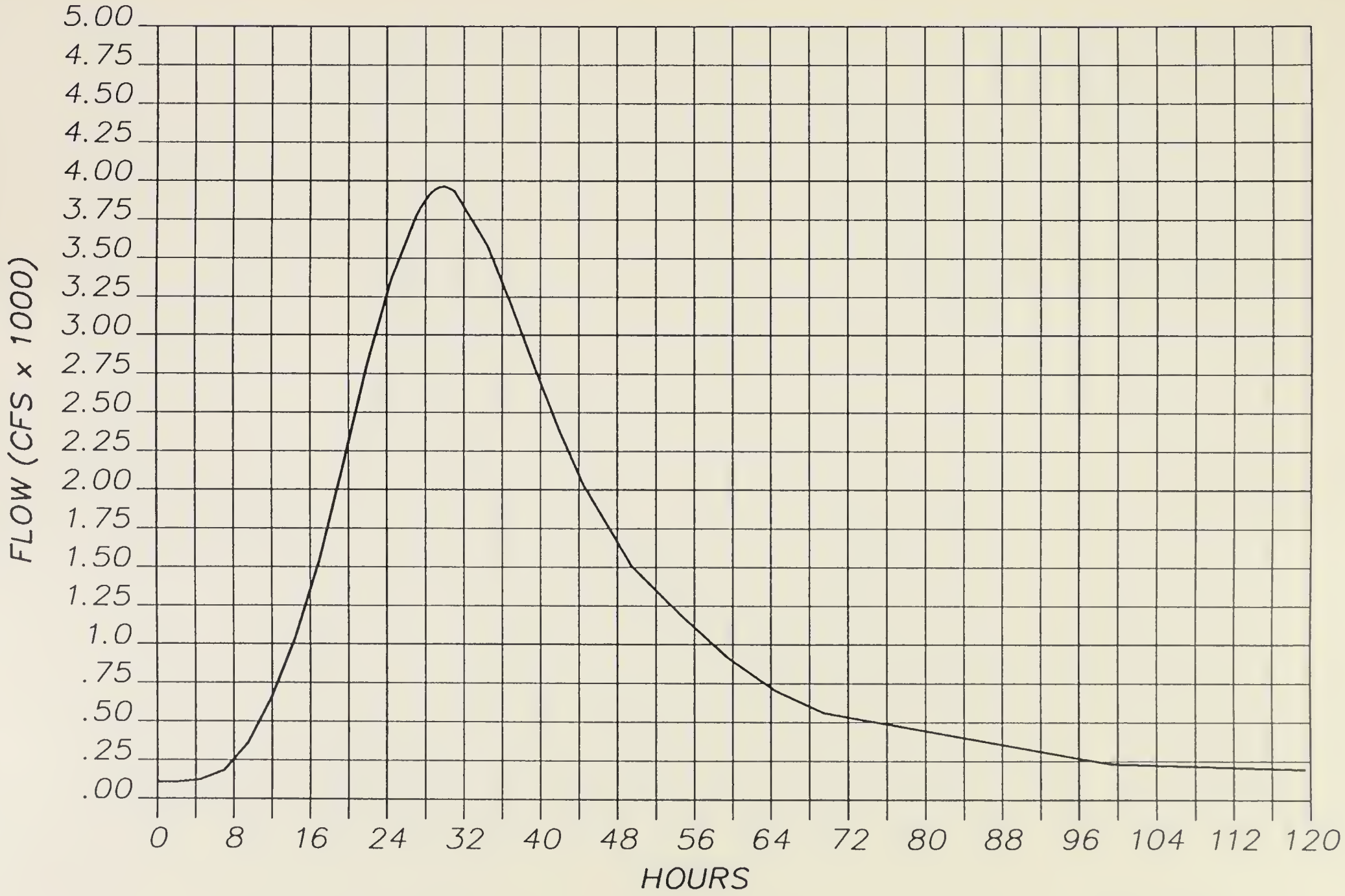


Figure 21
COMPUTED 1908 FLOOD; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

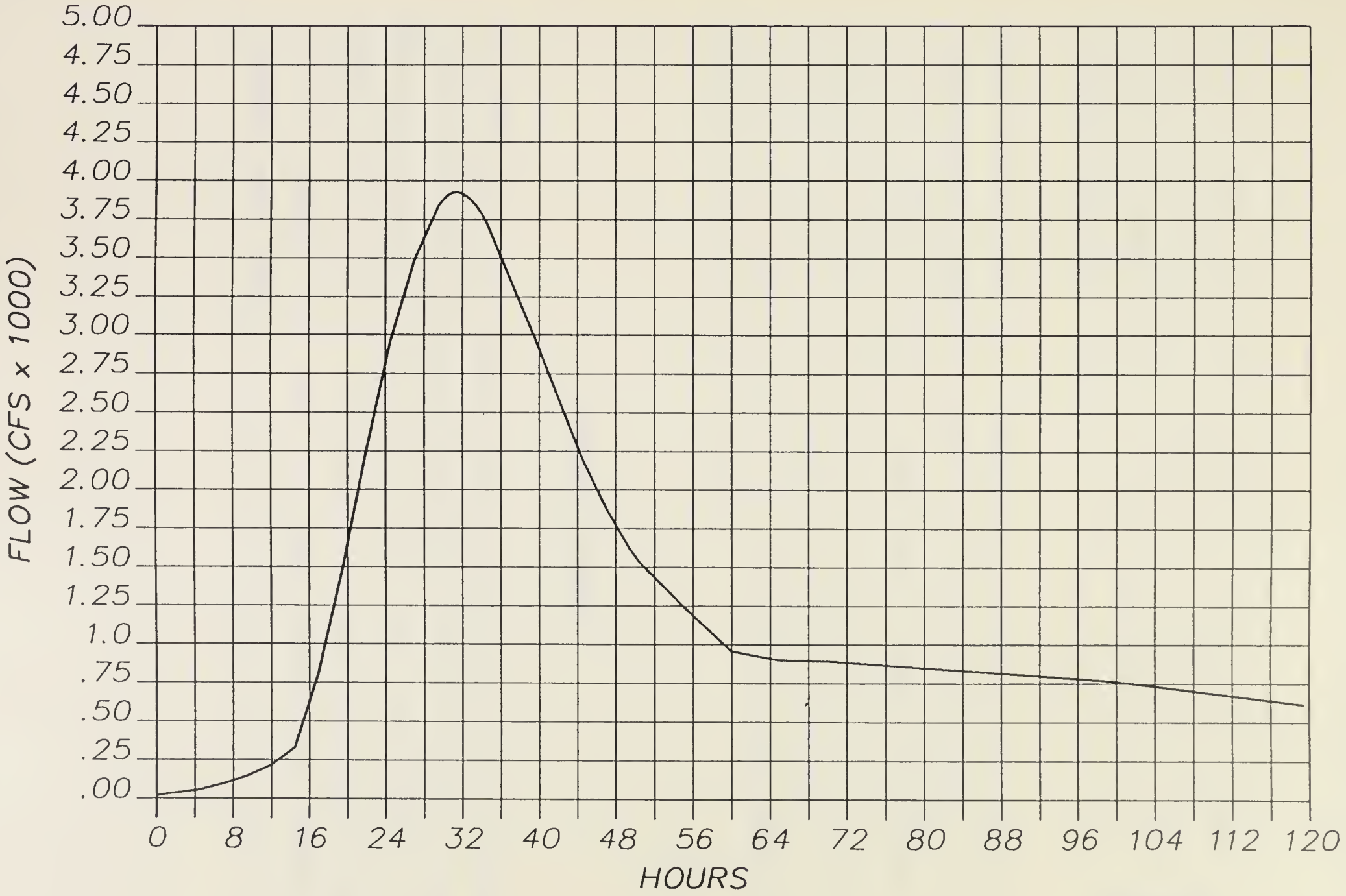


Figure 22
COMPUTED 1908 FLOOD; NODE 37; SILVER BOW CREEK GAGE ABOVE WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

10-, 25-, AND 100-YEAR DESIGN FLOOD COMPUTATIONS

The 10-, 25-, and 100-year design floods were computed using data obtained during the HEC-1 model calibration process and rainfall parameters from the NOAA Precipitation Atlas for Montana (Ref. 8).

Flows for the 10-, 25-, and 100-year events were determined by combining the respective May-June design hyetographs (rainfall) and the maximum extent of runoff-producing, snow-covered area calculated for the 1908, 1975, and 1981 events. The magnitudes of peak flows for these design events were consistent with the regional hydrologic analysis as described in the FREQUENCY ANALYSES section of this report.

HISTORIC FLOODS

Historically, the largest floods on the main stem of Silver Bow Creek have been spring rain/snowmelt floods in May or June. The four greatest floods were in May 1981, June 1975, June 1908, and June 1892. The causes of these floods were quite similar: heavy rain, warm air temperatures, and a saturated snowpack with extensive snow cover above 6,000 to 7,000 feet.

DESIGN SNOWMELT

The active snowmelt contributing area for the May-June period is limited to high elevation basins where late spring snowpacks exist and the underlying soil is saturated; and the contributing area is also limited by the area of associated shallow, rocky soils easily saturated by antecedent snowmelt.

Heavy rainfall events in Montana predominantly occur in May and June. Air temperatures are higher and storm track orientation and storm speed bring in moisture sources from the south. These combinations of factors restrict the area of active snowmelt contributing zones to the area above 7,000 feet and to a portion of the area between 6,000 and 7,000 feet.

Historical data revealed that snowmelt area and climatological factors reached above average values during major spring floods. In all cases, rainfall augmented the snowmelt runoff to produce the major floods of record. Therefore, one could expect that the recurrence interval of rainfall intensity/duration augmenting snowmelt would be the major factor controlling the recurrence interval of the flood event.

DESIGN RAINFALL

The NOAA Precipitation Atlas for Montana (Ref. 8) was used to construct synthetic 10-, 25-, and 100-year 24-hour design hyetographs. Since these hyetographs are based on annual daily

maximum precipitation, there was concern they would not be representative of the May and June precipitation values.

To confirm that the greatest rainfall events in the Butte area occur most often during the spring snowmelt period, a frequency analysis was conducted on maximum May-June daily rainfall values recorded during the 1898-1986 period. This analysis gave May-June 24-hour rainfall values that agreed with the calculated annual NOAA Atlas values.

To develop the final design hyetographs, storm patterns from the Butte recording station were analyzed for precipitation distribution during recorded May-June storms. By using these historical rainfall patterns, the 24-hour NOAA hyetographs were extended to a 72-hour storm. A 72-hour design storm event was required to calculate proper stream and pond routing values and flood volumes.

The resultant design hyetographs for the 10-, 25-, and 100-year storms are contained in the HEC-1 input files. Since the calibrated HEC-1 model contains elevation zones by 1000-foot increments, the average precipitation for the design storms is calculated for each subbasin using a weighted value based on these elevation zones. This allows for consideration of the increase in precipitation with increasing elevation as shown in Figures 2 and 9.

DESIGN FLOODS

The computer program HEC-1 was used to produce 10-, 25-, and 100-year design flood hydrographs and peaks for input to the HEC-2 backwater program and FLUVIAL-12 sedimentation model. Ten-, 25-, and 100-year 72-hour design hyetographs (at 1-hour time intervals) were constructed for modeling design flows on the main stem of Silver Bow Creek. The area of active snow-melt-producing zones, for design flows, was set to values similar to June 1908, June 1975, and May 1981. Air temperature, dew point temperature, and wind speed were similar to the June 1975 and May 1981 events.

Development of flood hydrographs using a calibrated model and synthetic design precipitation brings to light any uniqueness of the basin being studied as compared to a regional type frequency analysis. Most of the hydrographs that were calculated exhibit an initial peak, followed by a minor recession curve, then a larger (primary) peak, major recession, another minor peak, and final recession to base flow condition. This hydrograph shape resulted from upstream conditions within each subbasin that affected hydrograph combining (timing) and routing (attenuation). Also the design rainfall pattern was for a 3-day period. This time frame was used so that not only peak flow values were obtained for each frequency calculated, but the hydrograph volume was also calculated for use in Warm Springs ponds routing and design calculations. Figures 23 through 33 show design hydrographs as computed using the above criteria.

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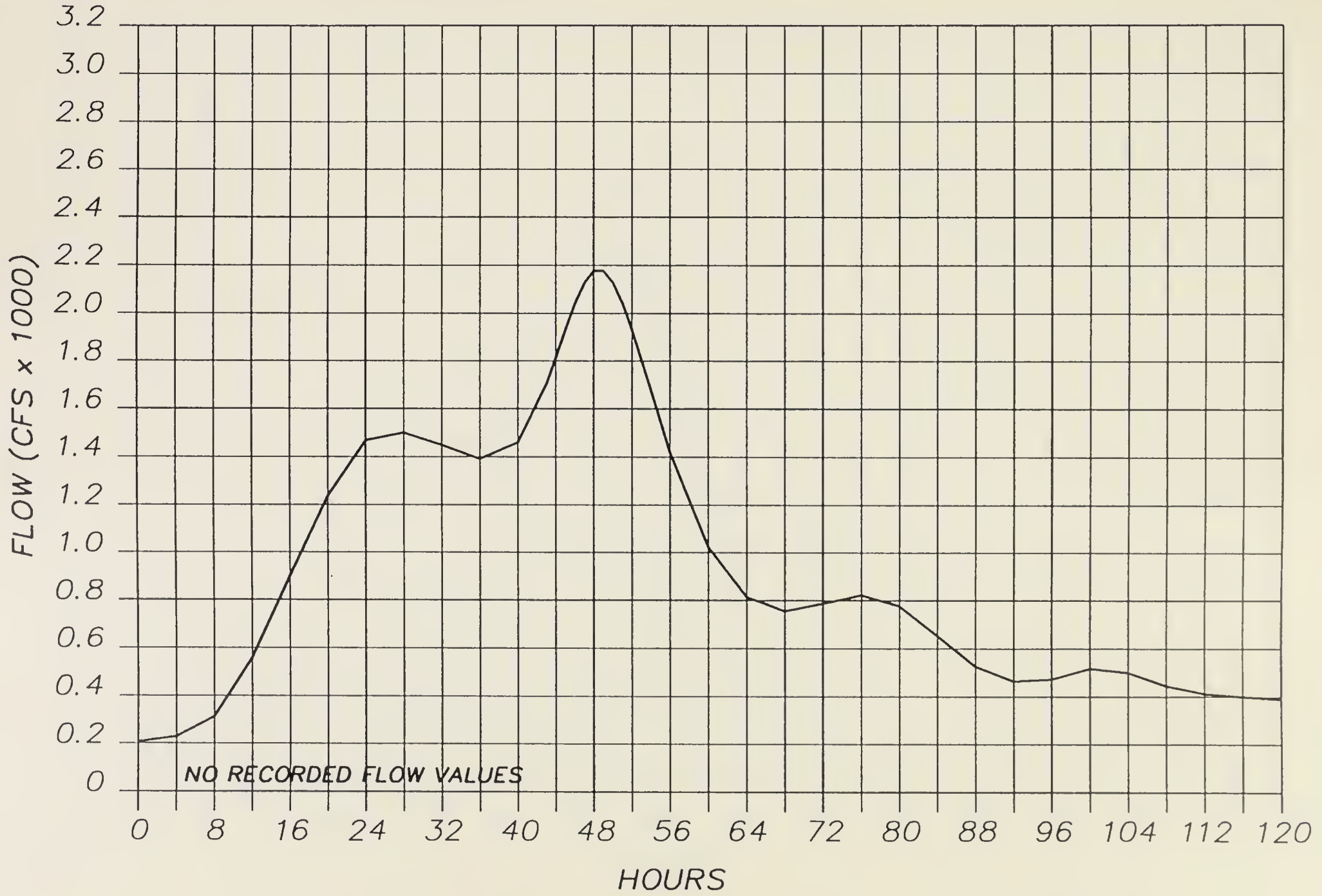

Figure 23
COMPUTED 10-YEAR FLOOD; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

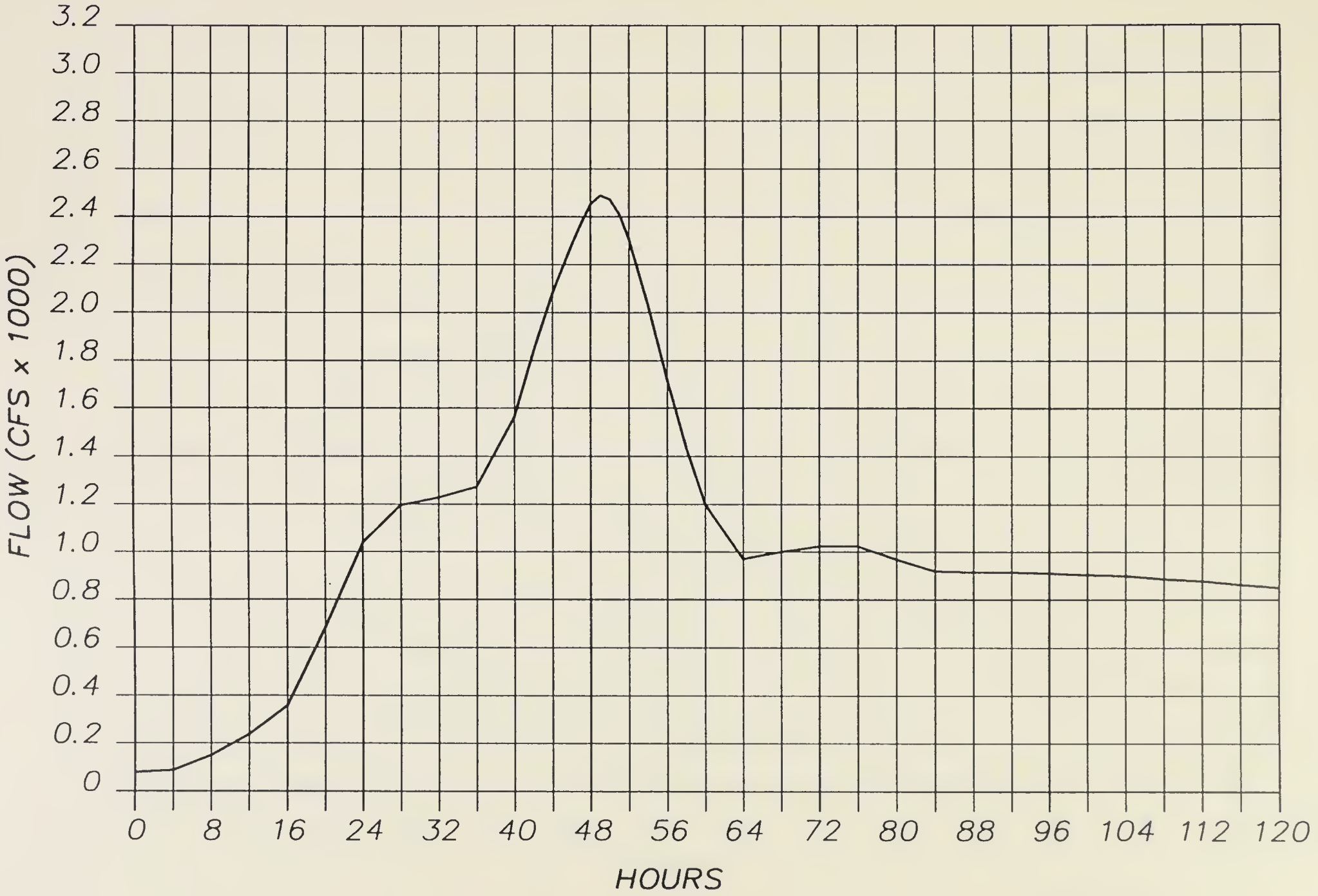

Figure 24
COMPUTED 10-YEAR FLOOD; NODE 37;
SILVER BOW CREEK GAGE ABOVE
WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

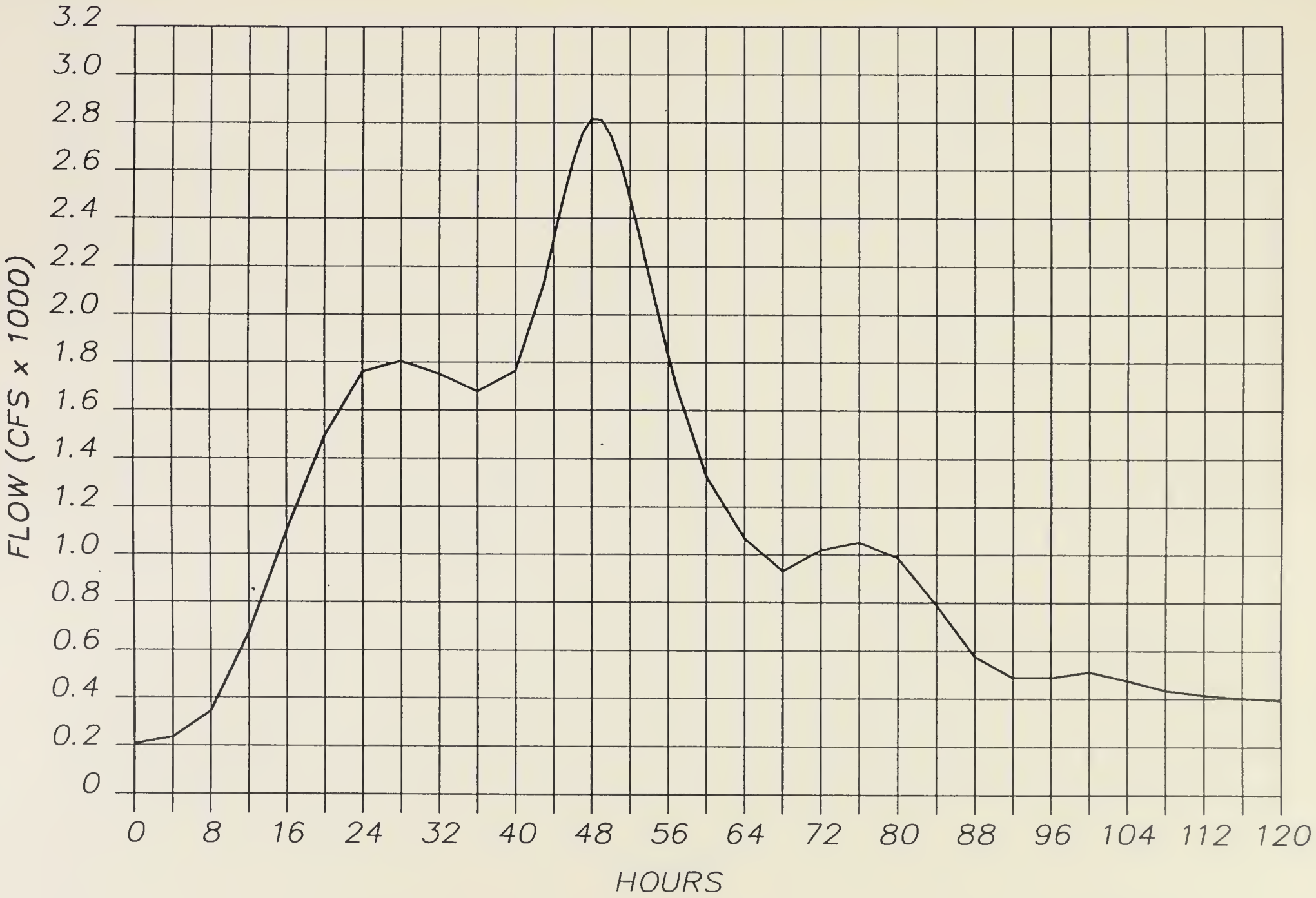

Figure 25
COMPUTED 25-YEAR FLOOD; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

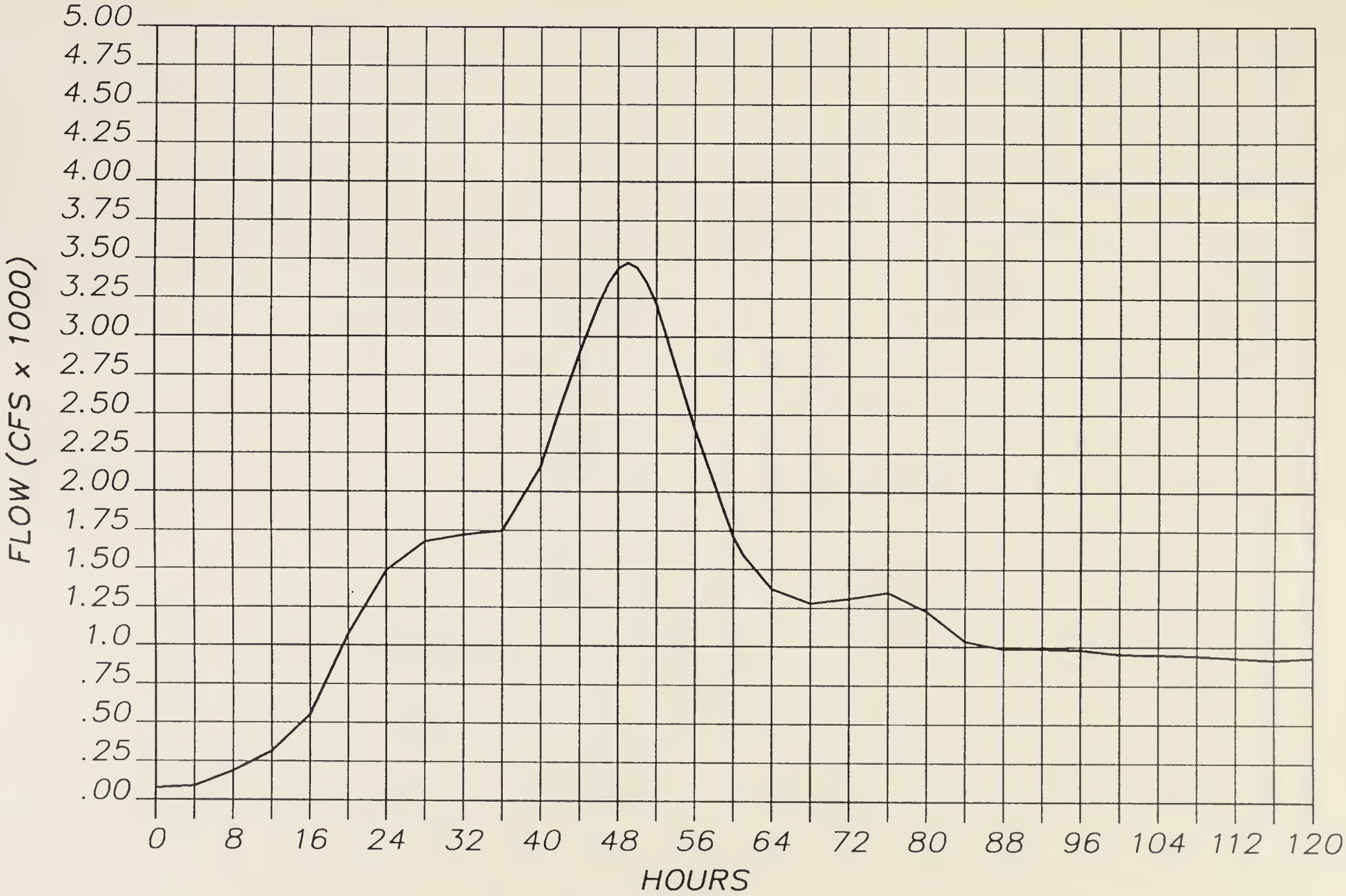

Figure 26
COMPUTED 25-YEAR FLOOD; NODE 37;
SILVER BOW CREEK GAGE ABOVE
WARM SPRING CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

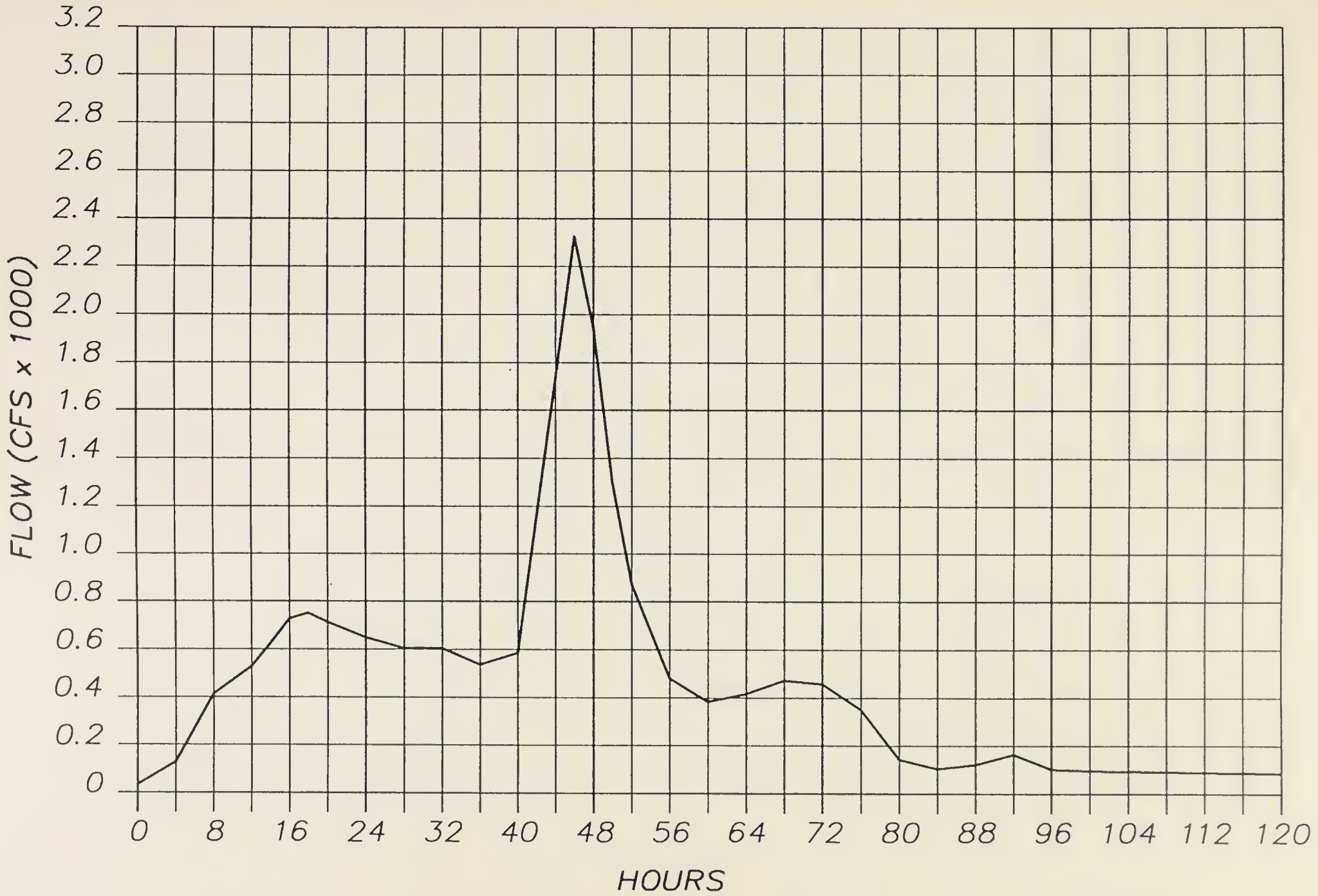

Figure 27
COMPUTED 100-YEAR FLOOD; NODE 12;
SILVER BOW CREEK GAGE BELOW
BLACKTAIL CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

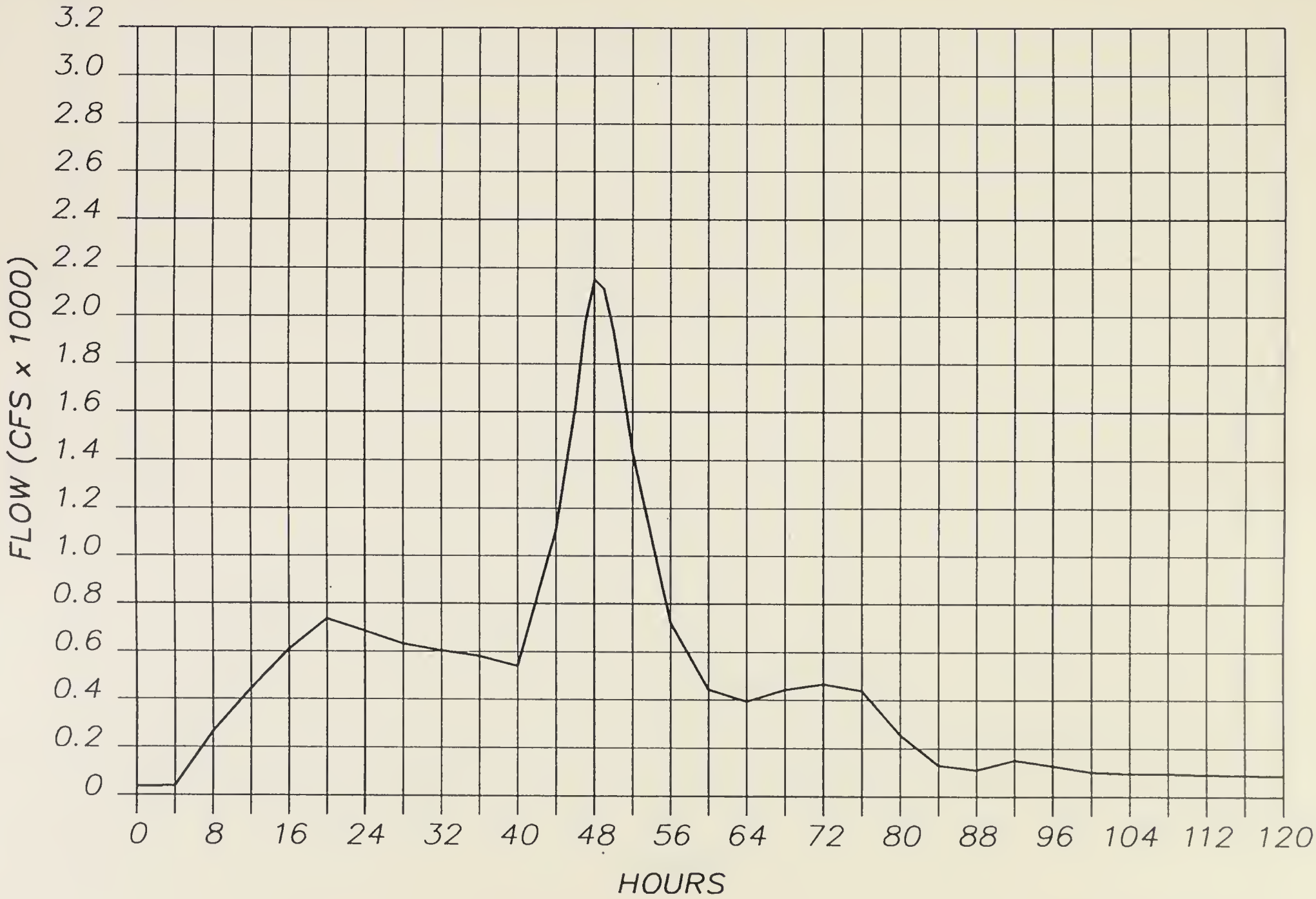

Figure 28
COMPUTED 100-YEAR FLOOD; NODE 14;
SILVER BOW CREEK ABOVE SAND CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

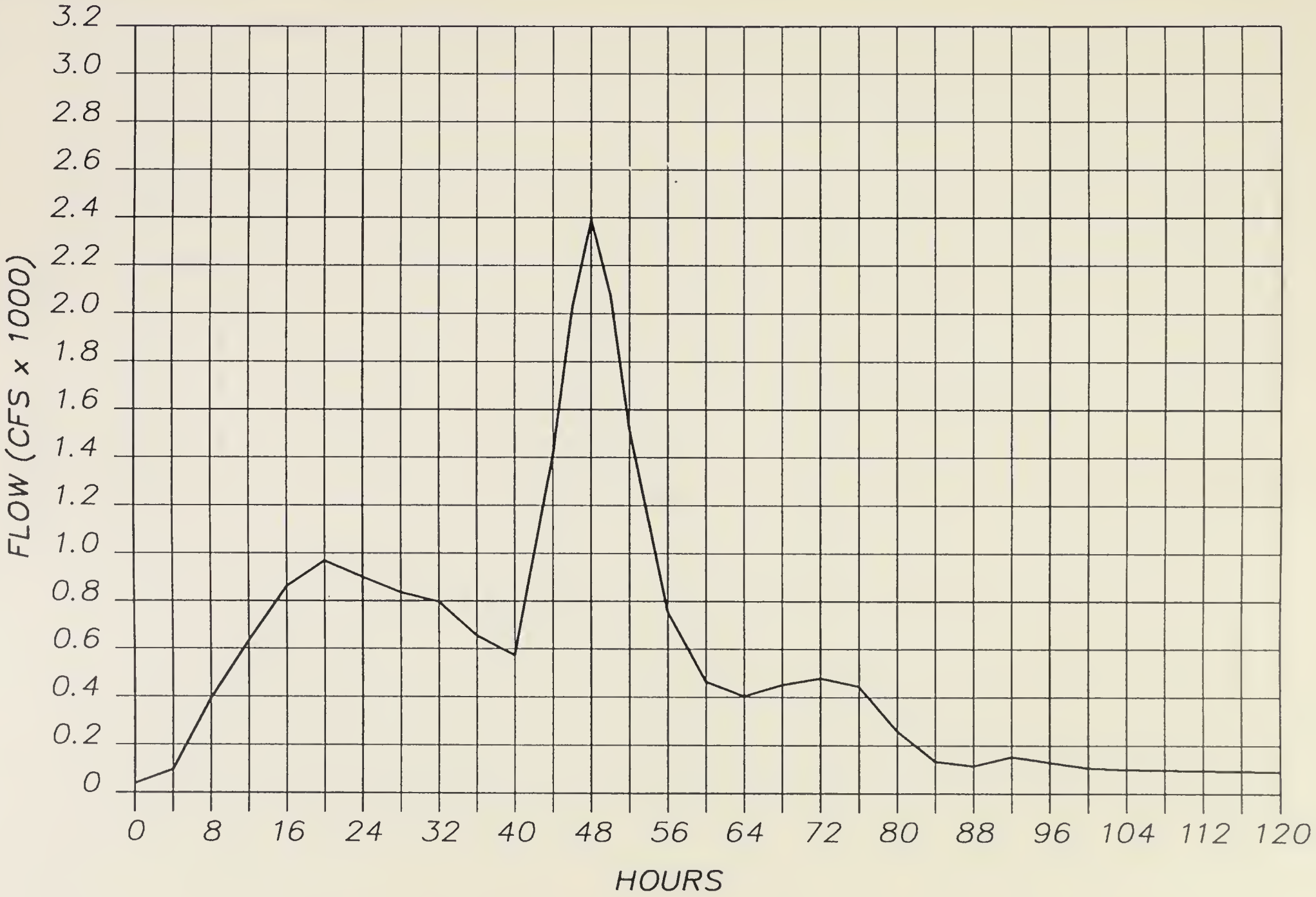

Figure 29
COMPUTED 100-YEAR FLOOD; NODE 16;
SILVER BOW CREEK BELOW SAND CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

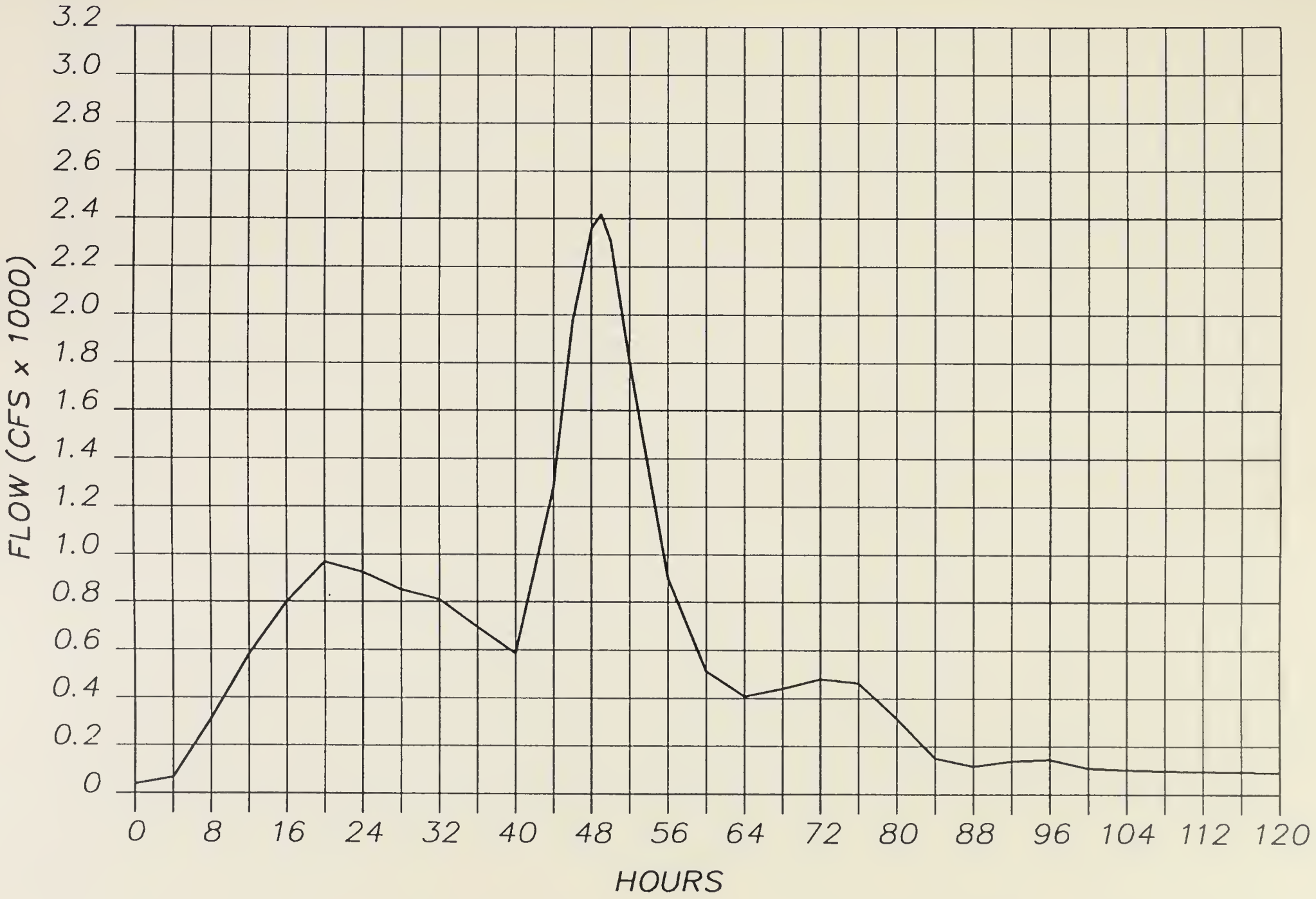

Figure 30
COMPUTED 100-YEAR FLOOD; NODE 18;
SILVER BOW CREEK ABOVE BROWNS GULCH
SILVER BOW CREEK FLOOD MODELING STUDY

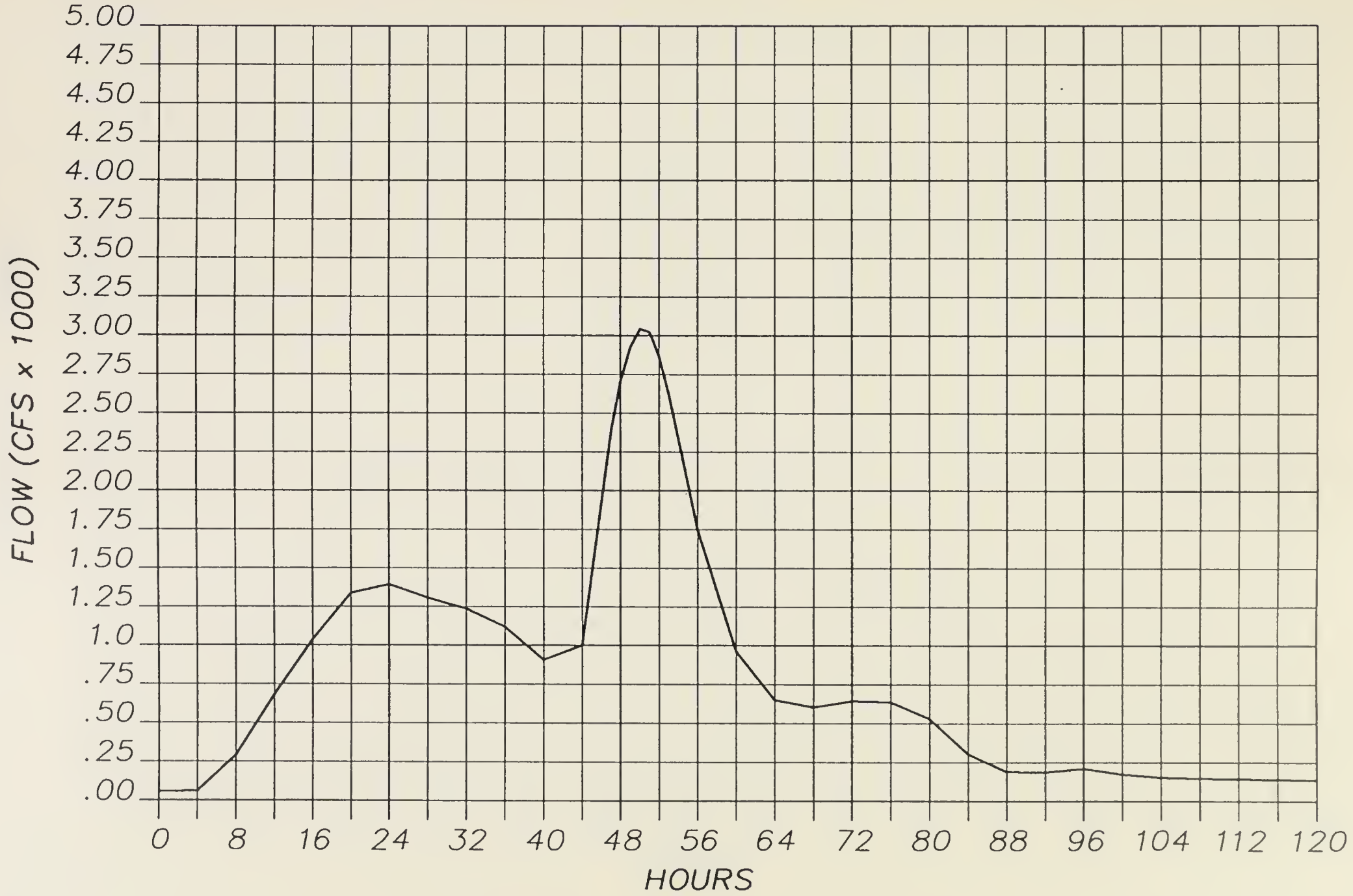

Figure 31
COMPUTED 100-YEAR FLOOD; NODE 22;
SILVER BOW CREEK ABOVE GERMAN GULCH
SILVER BOW CREEK FLOOD MODELING STUDY

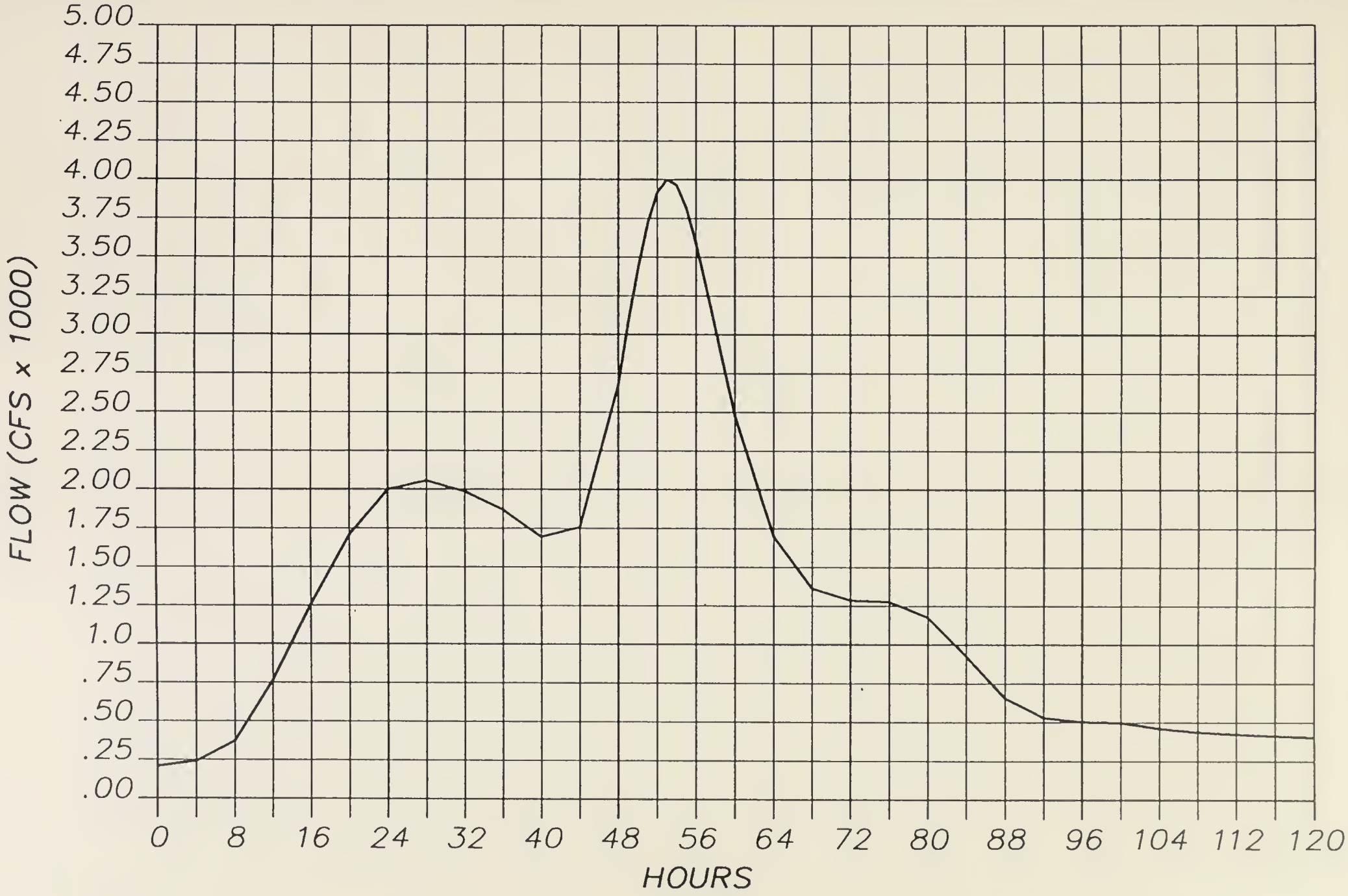

Figure 32
COMPUTED 100-YEAR FLOOD; NODE 26;
SILVER BOW CREEK ABOVE PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

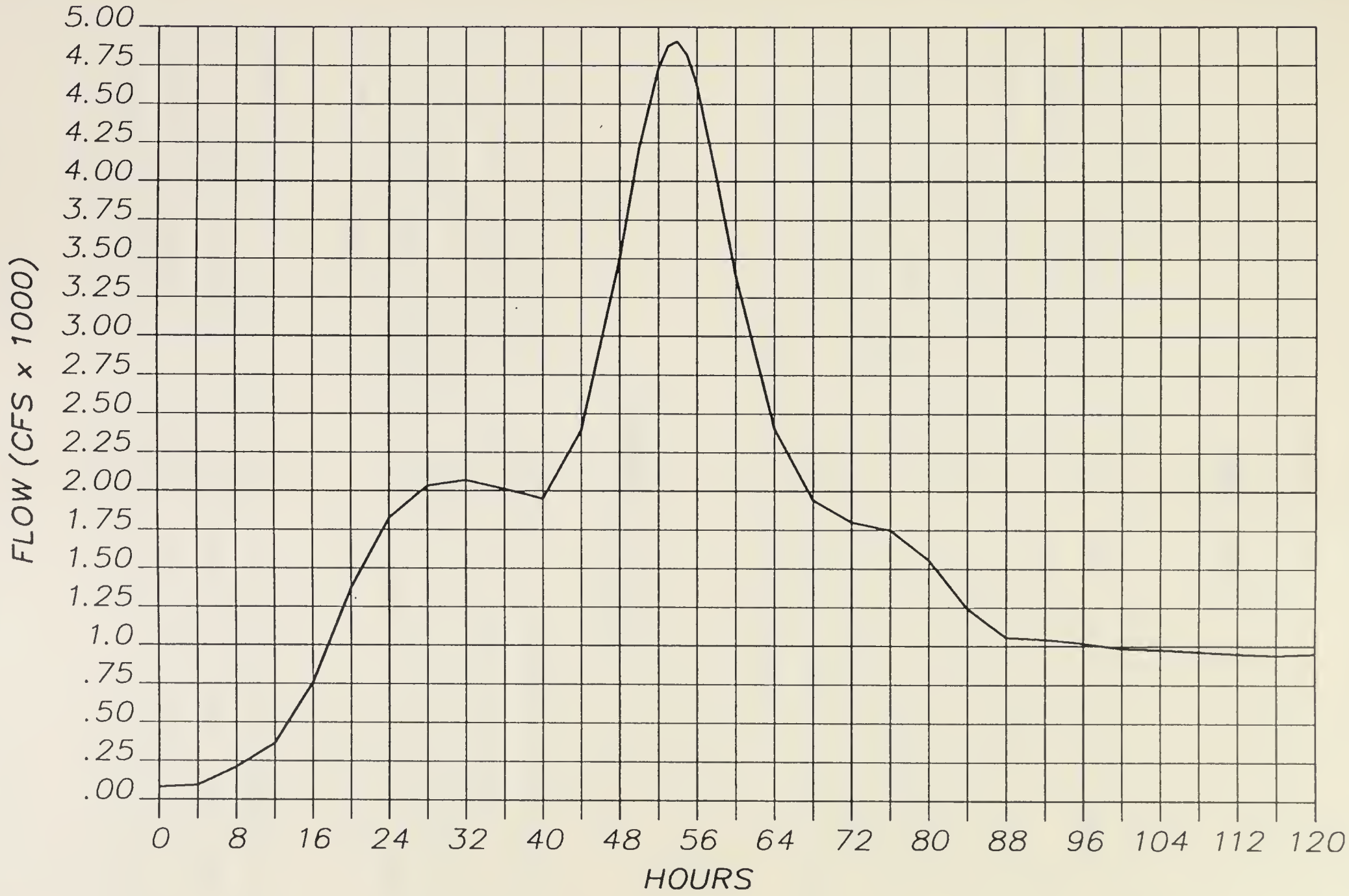

Figure 33
COMPUTED 100-YEAR FLOOD; NODE 37; SILVER BOW CREEK GAGE ABOVE WARM SPRINGS CREEK
SILVER BOW CREEK FLOOD MODELING STUDY

REGIONAL FREQUENCY ANALYSES

PEAK FLOWS

Flow-frequency relationships were prepared at 12 key gaging stations located in Silver Bow Creek and nearby basins. The locations of these stations are shown in Figure 34. Peak floods at these gages were, with rare exceptions, spring (May-June) snowmelt events augmented by rainfall. Peak flows due to winter events were rare and not of great enough magnitude to influence extrapolation of the relationships to higher recurrence intervals. However, winter events were considered in the Probable Maximum Flood (PMF) analysis.

FREQUENCY ANALYSIS

A regionalized frequency analysis was conducted on annual peak discharges obtained from the 12 key gaging stations. A log-Pearson Type III frequency analysis was made on these known discharges using procedures as outlined by the U.S. Water Resources Council (Ref. 9).

Annual recorded peak flows for each gage were compiled, ranked, and assigned positions for log-normal plotting. As shown in Figures 35 through 46, straight line data fitting (zero skew) resulted in the best fit curve for the larger floods observed at all gages.

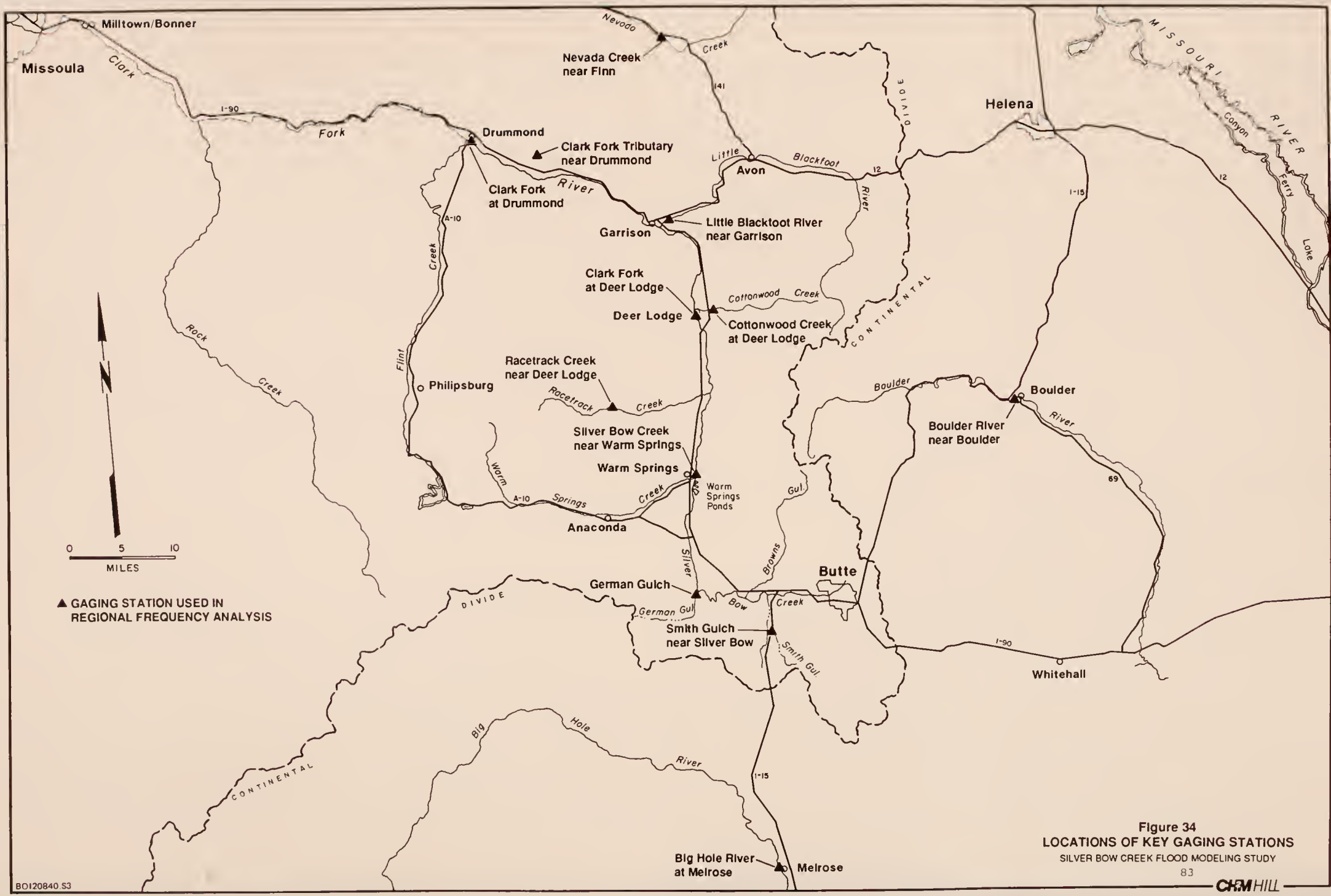

Figure 34
LOCATIONS OF KEY GAGING STATIONS
SILVER BOW CREEK FLOOD MODELING STUDY

BOI20840.S3

CH2M HILL

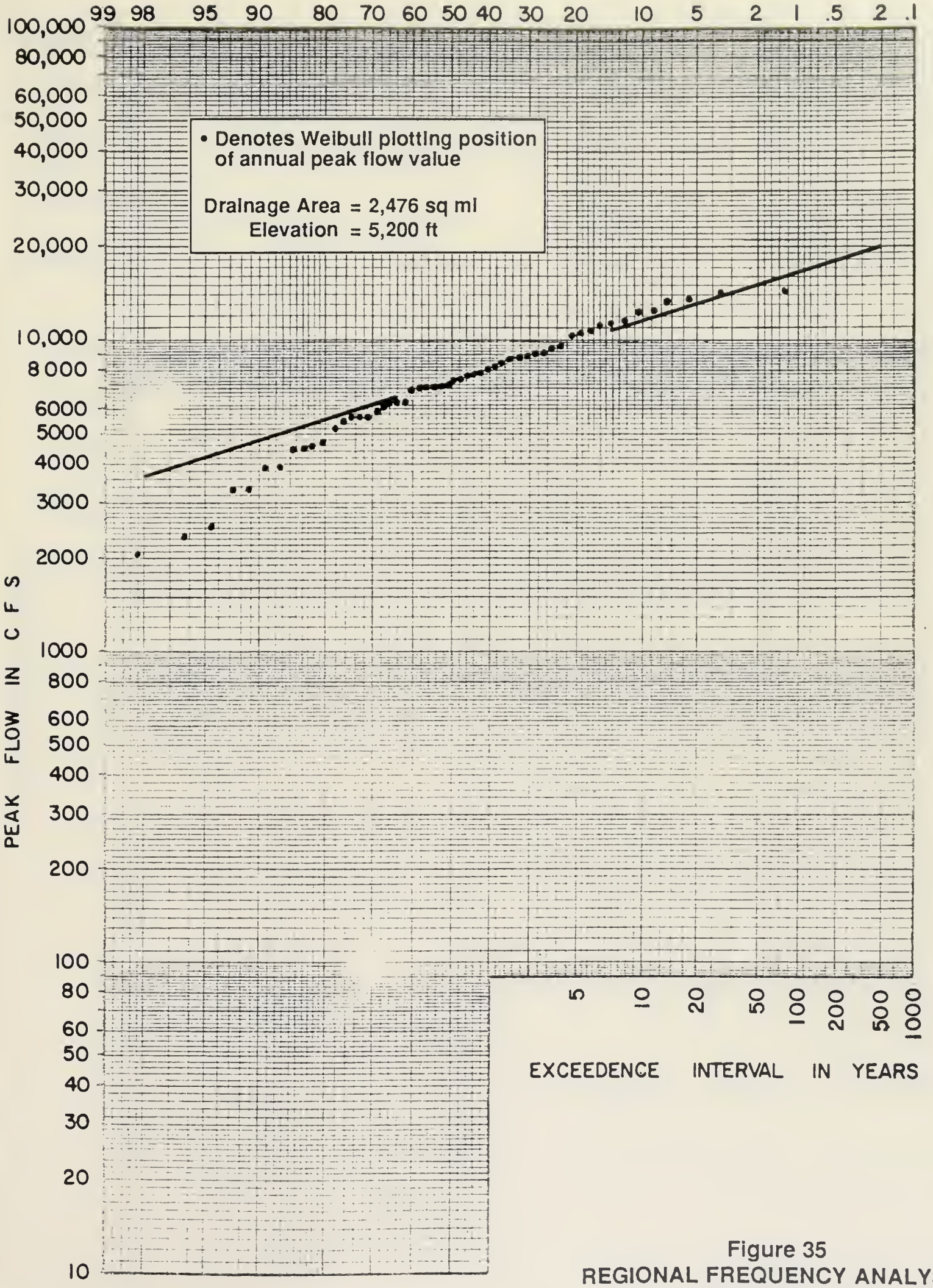

Figure 35
REGIONAL FREQUENCY ANALYSIS;
BIG HOLE RIVER AT MELROSE
SILVER BOW CREEK FLOOD MODELING STUDY

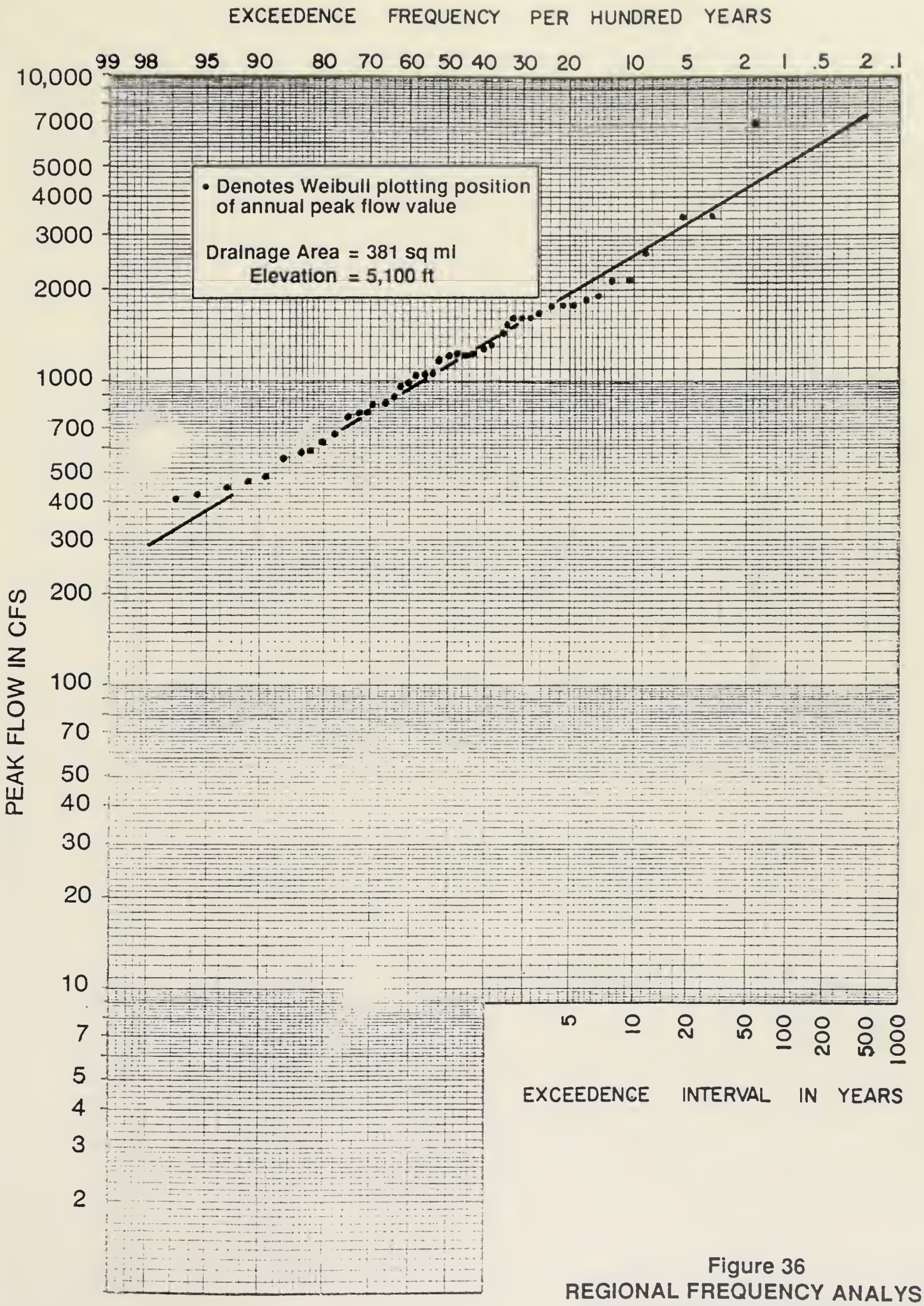

Figure 36
REGIONAL FREQUENCY ANALYSIS;
BOULDER RIVER NEAR BOULDER
SILVER BOW CREEK FLOOD MODELING STUDY

EXCEEDENCE FREQUENCY PER HUNDRED YEARS

99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .2 .1

100,000
80,000
60,000
50,000
40,000
30,000
20,000
10,000
8 000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10

PEAK FLOW IN C F S

• Denotes Weibull plotting position of annual peak flow value

Drainage Area = 1,005 sq mi
Elevation = 4,675 ft

5 10 20 50 100 200 500 1000

EXCEEDENCE INTERVAL IN YEARS

Figure 37
REGIONAL FREQUENCY ANALYSIS;
CLARK FORK AT DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

BO120840.S3

CH2M HILL

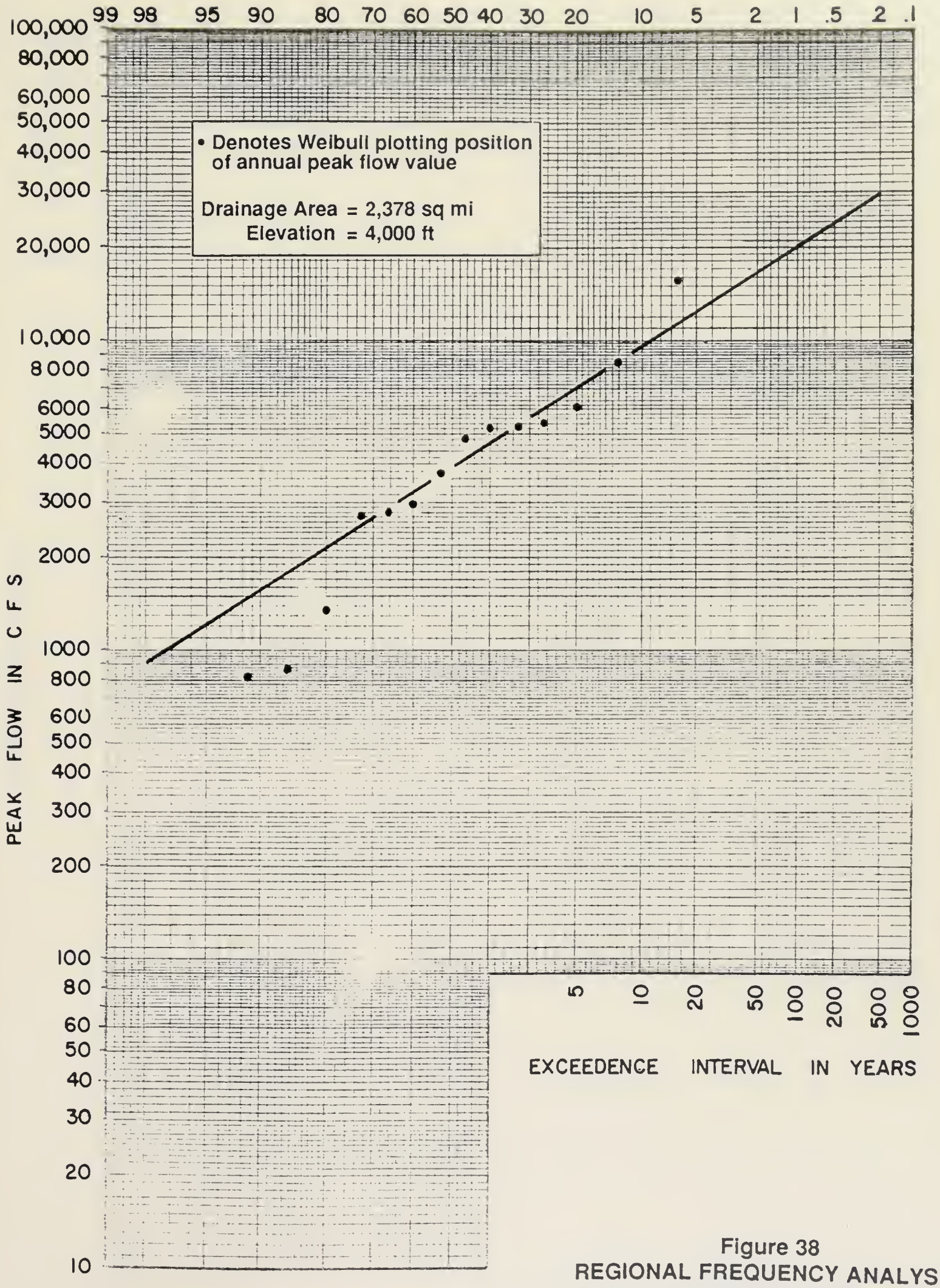

Figure 38
REGIONAL FREQUENCY ANALYSIS;
CLARK FORK AT DRUMMOND
SILVER BOW CREEK FLOOD MODELING STUDY

BO120840.S3

CH2M HILL

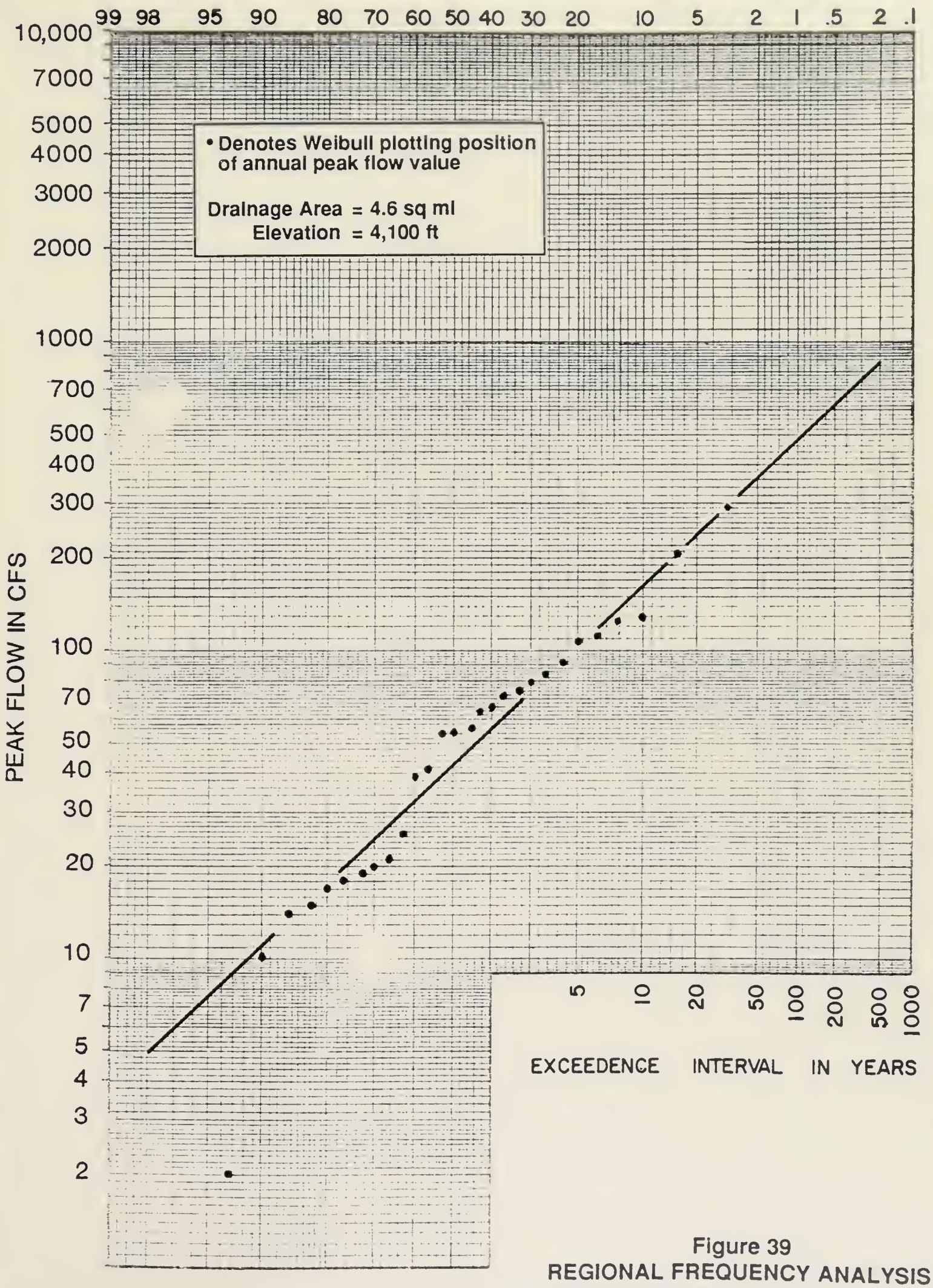

Figure 39
REGIONAL FREQUENCY ANALYSIS;
CLARK FORK TRIBUTARY NEAR DRUMMOND
SILVER BOW CREEK FLOOD MODELING STUDY

BO120840.S3

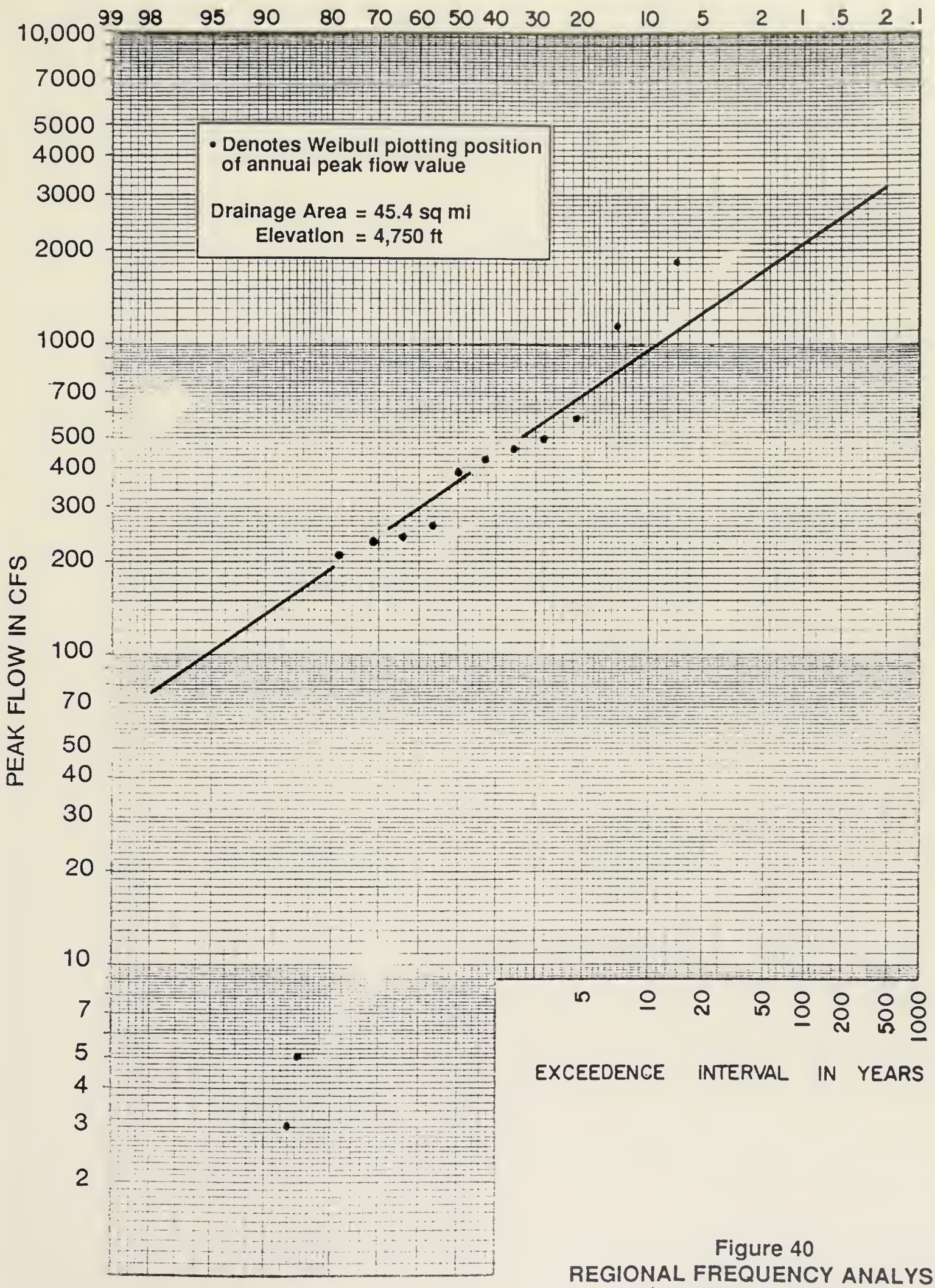

Figure 40
REGIONAL FREQUENCY ANALYSIS;
COTTONWOOD CREEK AT DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

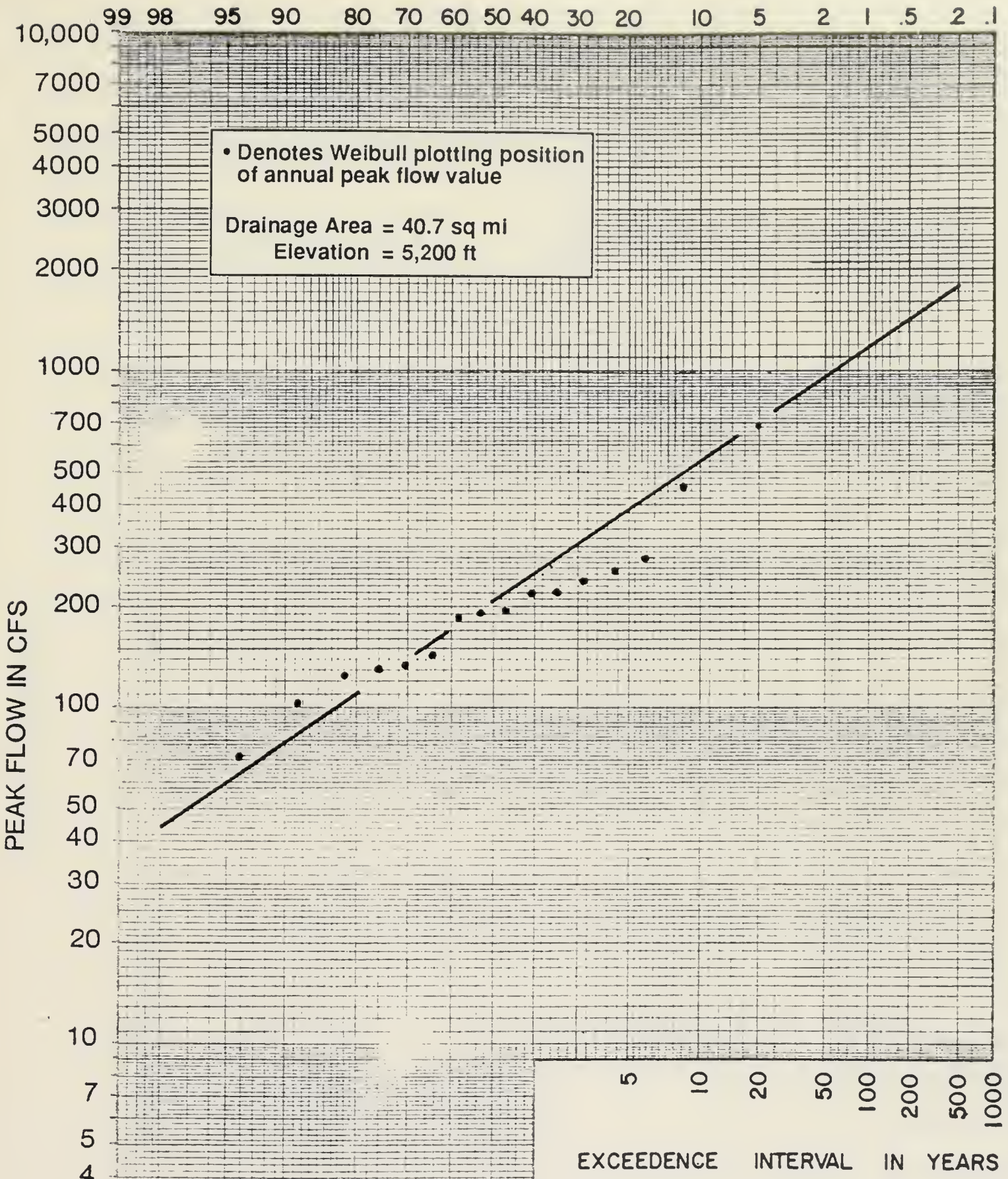

Figure 41
REGIONAL FREQUENCY ANALYSIS; GERMAN GULCH
SILVER BOW CREEK FLOOD MODELING STUDY

BO120840.S3

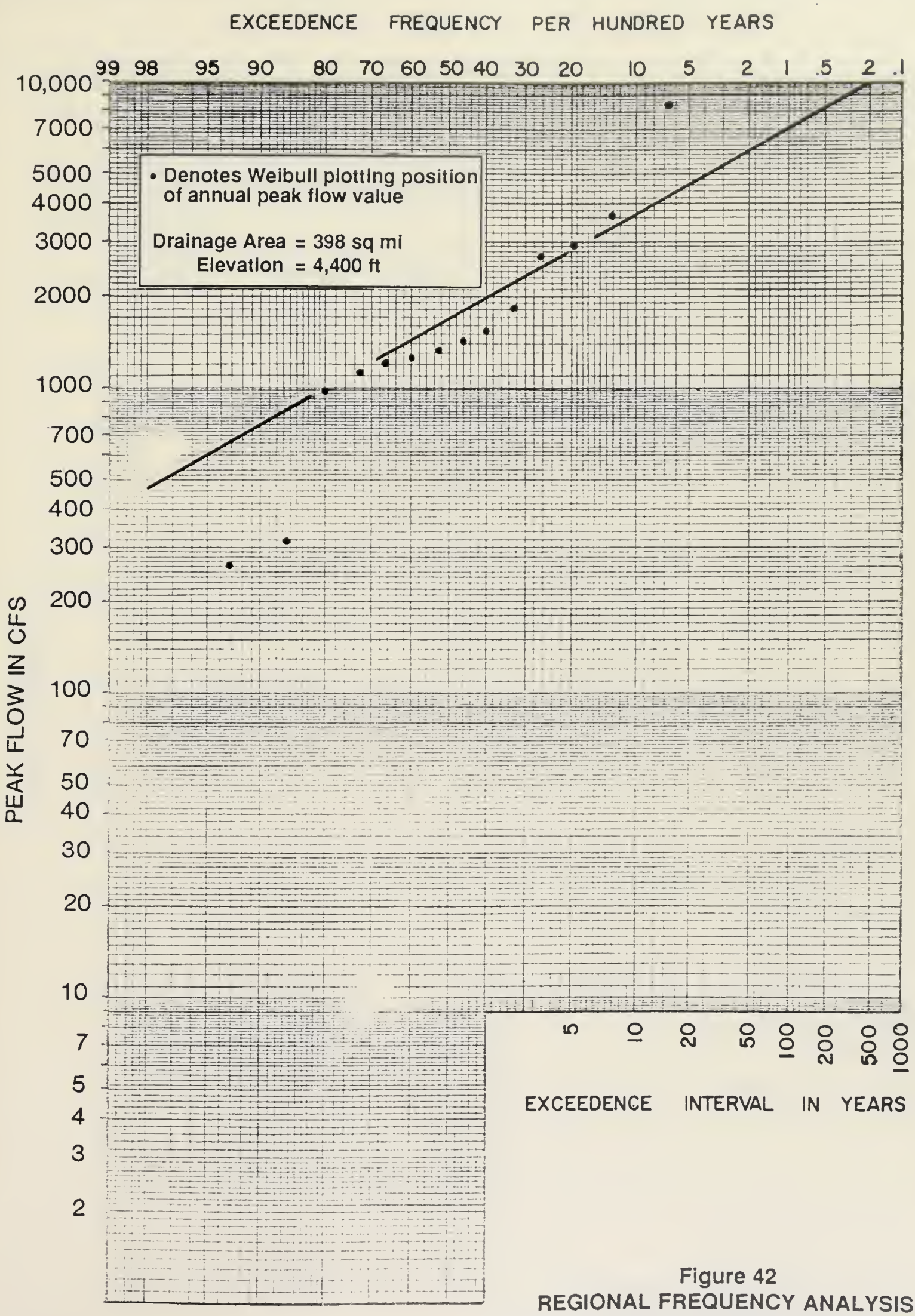

Figure 42
REGIONAL FREQUENCY ANALYSIS;
LITTLE BLACKFOOT RIVER NEAR GARRISON
SILVER BOW CREEK FLOOD MODELING STUDY

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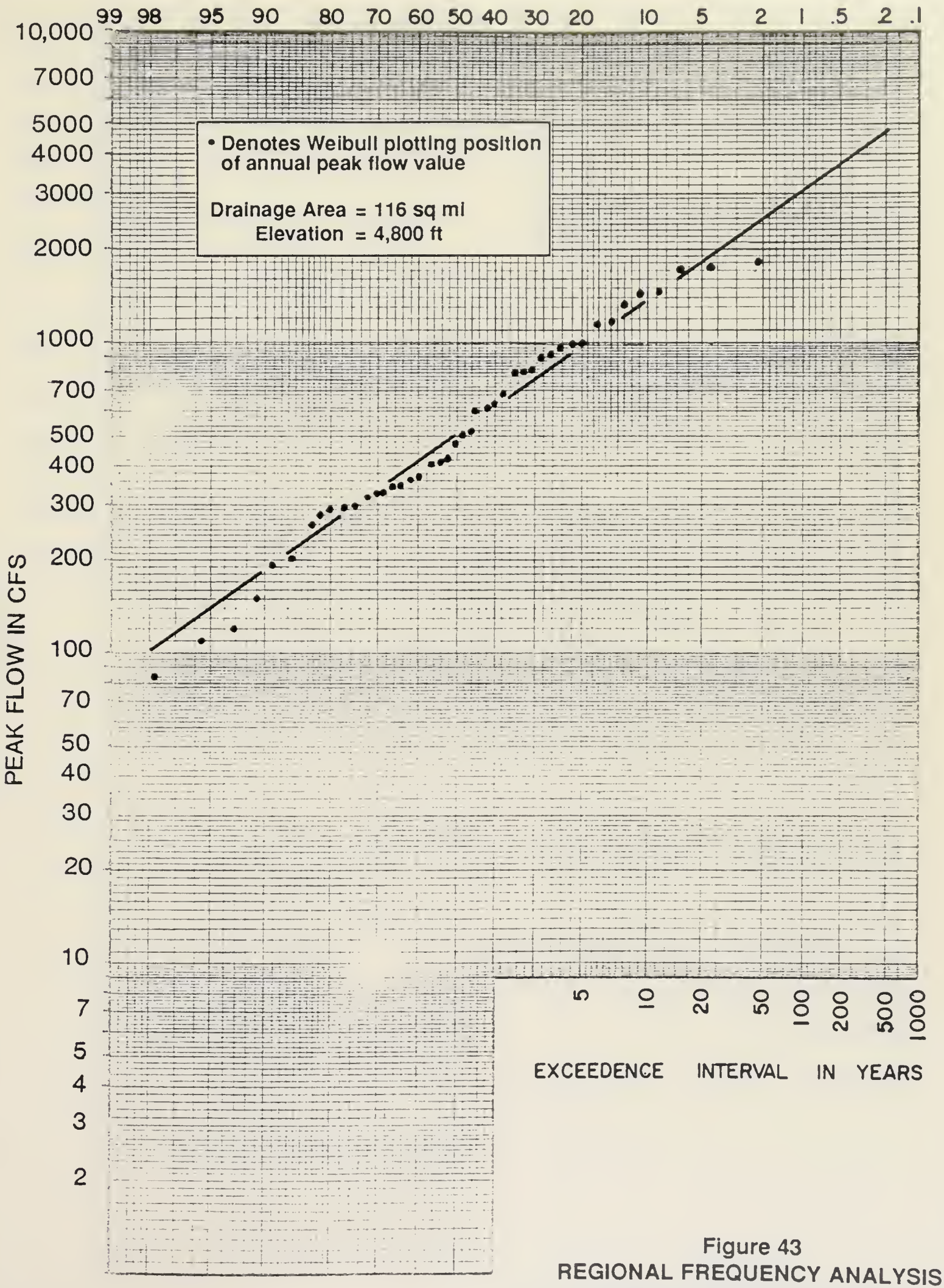

Figure 43
REGIONAL FREQUENCY ANALYSIS;
NEVADA CREEK NEAR FINN
SILVER BOW CREEK FLOOD MODELING STUDY

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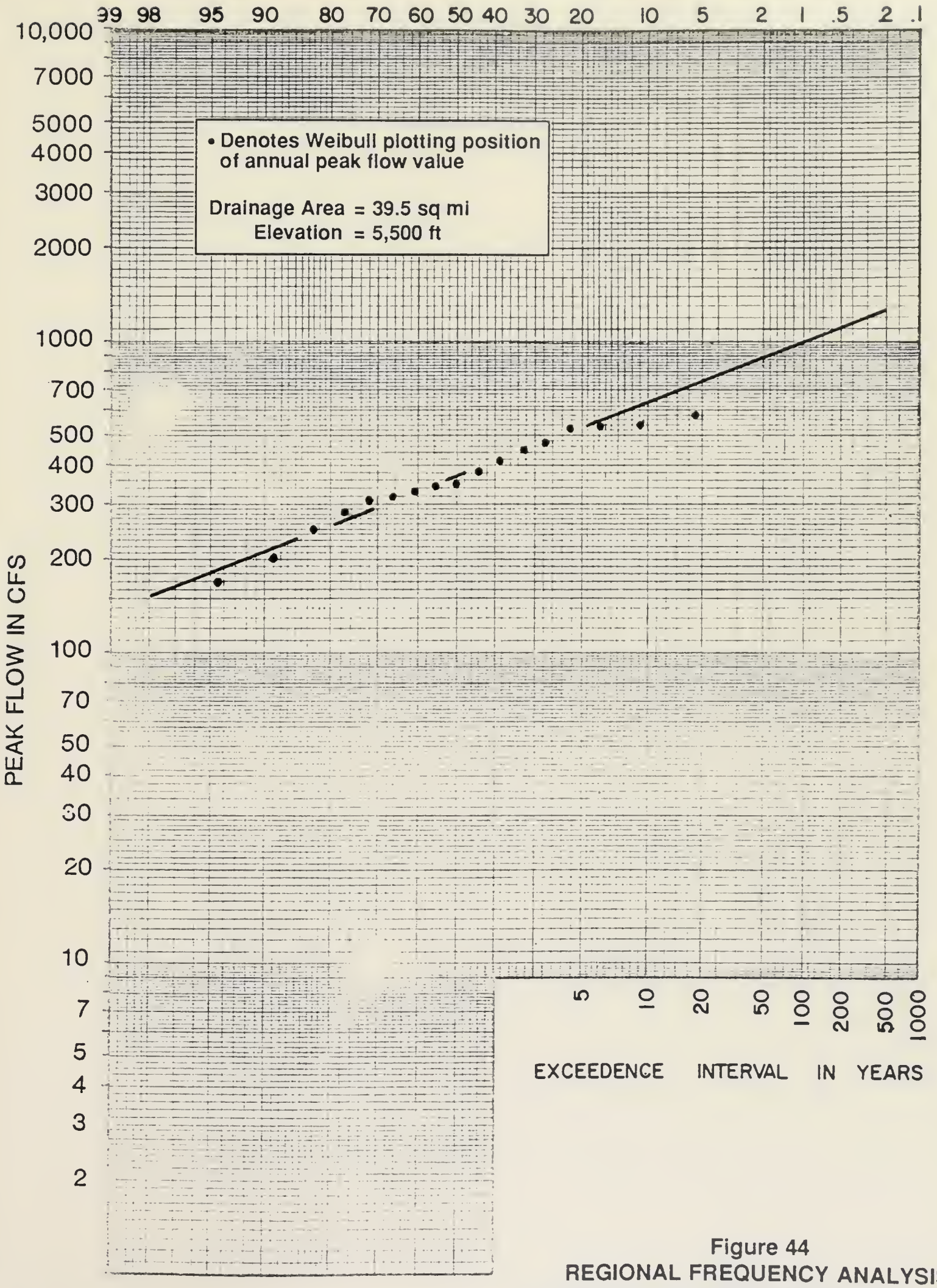

Figure 44
REGIONAL FREQUENCY ANALYSIS;
RACETRACK CREEK NEAR DEER LODGE
SILVER BOW CREEK FLOOD MODELING STUDY

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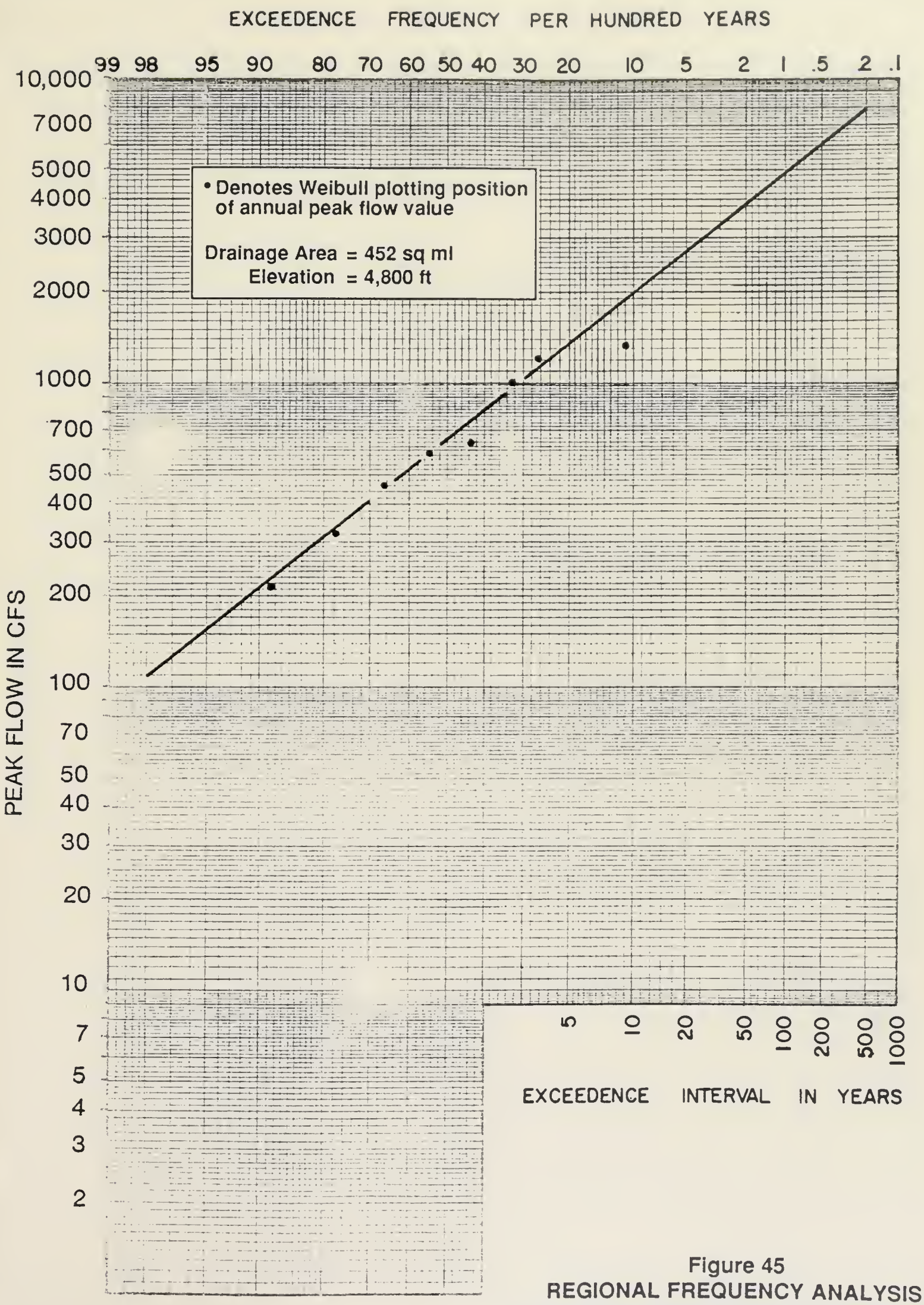

Figure 45
REGIONAL FREQUENCY ANALYSIS;
SILVER BOW CREEK NEAR WARM SPRINGS
SILVER BOW CREEK FLOOD MODELING STUDY

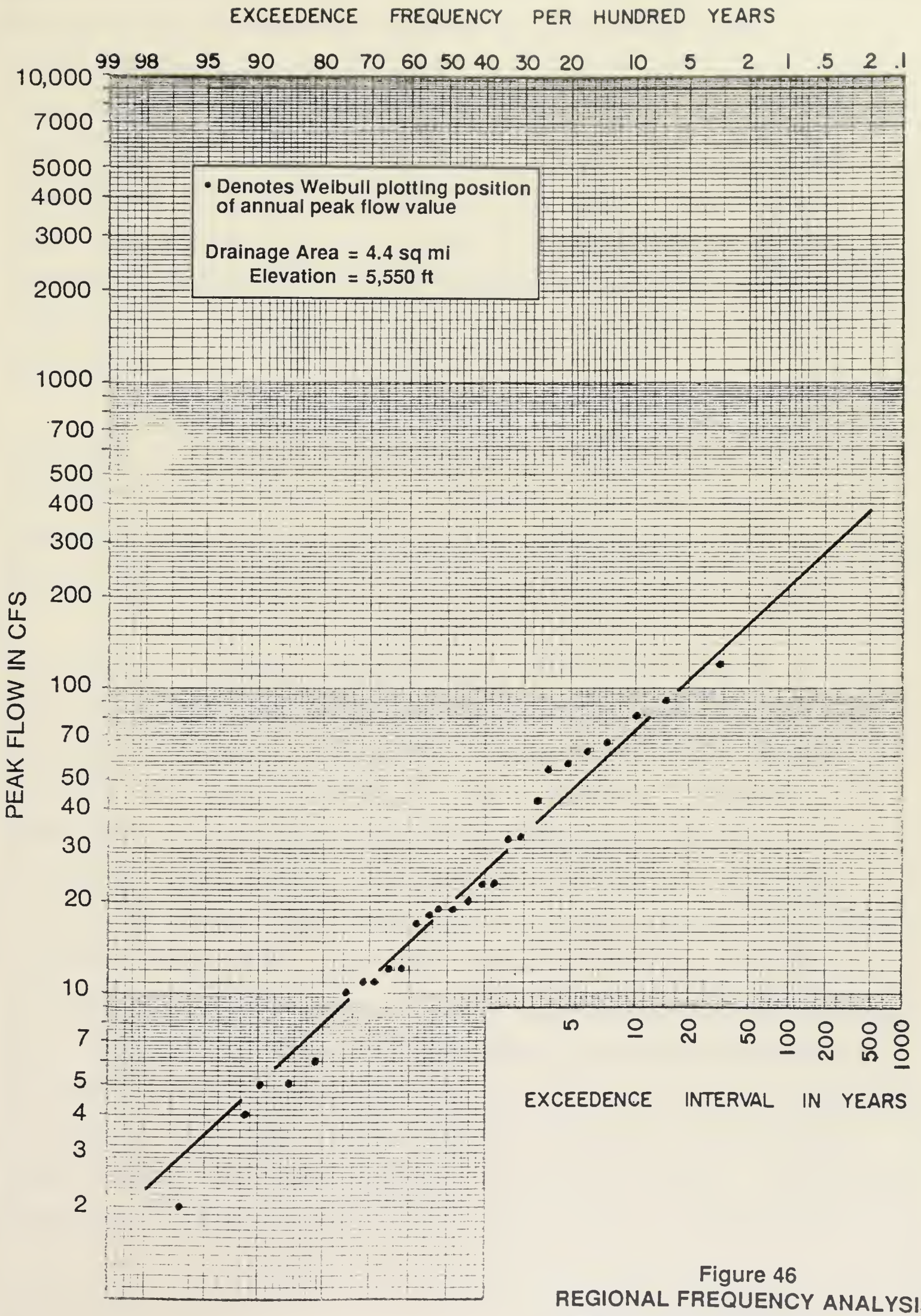

Figure 46
REGIONAL FREQUENCY ANALYSIS;
SMITH GULCH NEAR SILVER BOW
SILVER BOW CREEK FLOOD MODELING STUDY

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Nine of the gage records showed a consistent ratio of 10:25:100-year recurrence peaks. Racetrack Creek and Big Hole River showed flatter curve slopes (lower 10:25:100-year ratios) since they had a higher proportion of high elevation snowmelt zones which consistently produced high runoff nearly every year. The Silver Bow Creek gage below the ponds showed a steeper slope (greater 10:25:100-year ratios) due to peak flow regulation by the ponds, which would be more effective for lower peaks.

Using the values from the frequency analyses, envelope curves were developed that show the estimated range in flow value of a given drainage area for the specific frequency flood (Figure 47).

As previously stated, calculation of flood hydrographs using a calibrated model and design precipitation brings to light any uniqueness of runoff conditions for the basin being studied as compared to a regional-type frequency analysis. However, a comparison of 10-, 25-, and 100-year computed (HEC-1) hydrograph peaks (Table 8) showed that they were consistent with the envelope curves developed from the regional frequency analysis (Figure 47). The flood peaks for Silver Bow Creek upstream of the ponds were slightly below the regional curves. This was expected since the area of high elevation snowmelt is relatively small in the upper Silver Bow Creek basin, compared to stream basins used in the regional analysis, until inflow occurs from German Gulch and Mill and Willow Creeks. Also, the design precipitation used in the models was for the entire

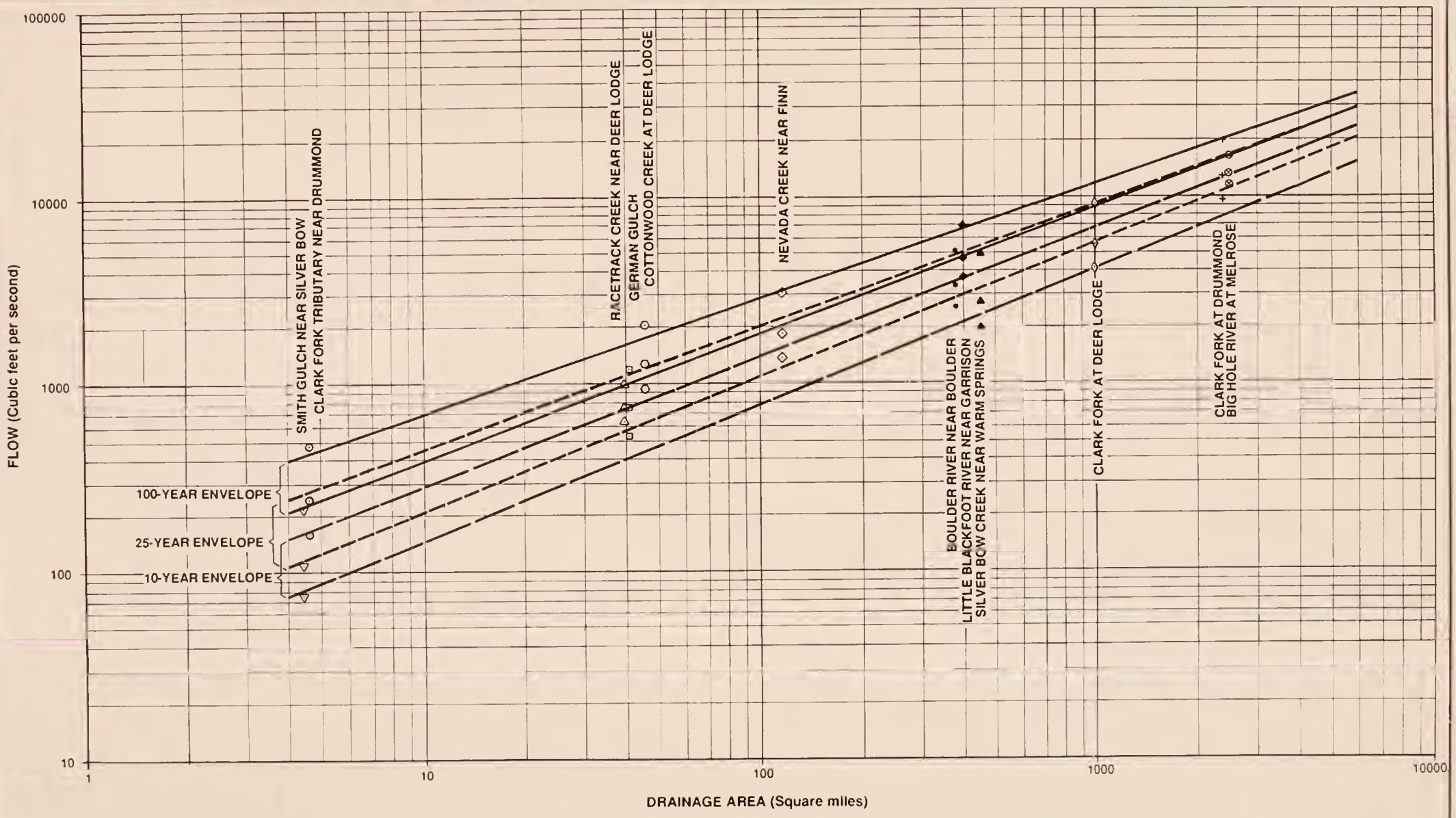

Figure 47
REGIONAL FREQUENCY ANALYSIS
10-, 25-, 100-YEAR ENVELOPE CURVES
SILVER BOW CREEK FLOOD STUDY

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Table 8
SILVER BOW CREEK MODEL PEAK FLOW CALCULATIONS COMPARED WITH
REGIONAL FREQUENCY ENVELOPE CURVES

Location	Area (sq mi)	Model Node	10-Year Recurrence (cfs)			25-Year Recurrence (cfs)			100-Year Recurrence (cfs)		
			Lower	Upper	Model	Lower	Upper	Model	Lower	Upper	Model
Silver Bow Creek Below Blacktail Creek	103	12	800	1,450	1,270	1,150	2,050	1,570	1,900	3,000	2,330
Silver Bow Creek Below Canada Creek	117	14	850	1,550	1,180	1,200	2,200	1,450	2,050	3,250	2,160
Silver Bow Creek Above Browns Gulch	166	18	1,100	2,000	1,240	1,600	2,800	1,560	2,600	4,000	2,420
Silver Bow Creek Above German Gulch	266	22	1,550	2,750	1,580	2,200	3,800	1,990	3,600	5,400	3,050
Silver Bow Creek Above Diversion Works	347	26	1,900	3,300	2,190	2,700	4,500	2,820	4,300	6,300	4,000
Silver Bow Creek At Old USGS Gage Site Above Warm Springs Creek	452	37	2,300	3,900	2,490	3,300	5,400	3,480	5,000	7,400	4,950

NOTE: Values as calculated by the model at Nodes 12, 14, and 18 decrease because of hydrograph routing, hydrograph timing, and limited local inflow.

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basin and not for each individual specific drainage basin. Rainfall developed for each individual basin would increase if a flood analysis was being conducted for the specific smaller watershed. Since the overall drainage was being studied, the rainfall was considered to occur over the entire drainage.

Table 9 shows the 10-, 25-, and 100-year flood peaks from the frequency analyses and the maximum observed flood peak.

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Table 9
REGIONAL FREQUENCY ANALYSIS

USGS Gage Location	Gage Elevation	Gage Number	Years of Record	Basin Area (sq mi)	Peak Flow (cfs) 10-year	25-Year	100-Year	Maximum Observed Flow (cfs)/Date
Big Hole River at Melrose	5200	06025500	1924-86	2,476	11,750	13,500	16,500	14,300 (6-10-72)
Boulder River Near Boulder	5100	06033000	1919-32, 1934-72	381	2,600	3,400	5,200	7,000 (5-22-81)
Smith Gulch Near Silver Bow	5550	12323300	1959-86	4.4	75	110	220	123 (12-23-64)
German Gulch	5200	12323500	1954-69, 1975	40.7	530	750	1,200	692 (6-19-75)
Silver Bow Creek Near Warm Springs	4800	12323750	1971-79	452	2,000	2,800	5,000	1,320 (6-20-75)
Racetrack Creek Near Deer Lodge	5500	12324100	1956-73, 1975	39.5	640	770	1,000	580 (6-19-75)
Clark Fork At Deer Lodge	4675	12324200	1978-86	1,005	4,100	5,600	9,200	2,500 (5-22-81)
Cottonwood Creek at Deer Lodge	4750	12324250	1975-86	45.4	950	1,300	2,100	1,820 (5-22-81)
Little Blackfoot River Near Carrison	4400	12324590	1972-86	398	3,700	4,800	7,000	8,650 (5-22-81)
Clark Fork Tributary Near Drummond	4100	12324700	1958-86	4.6	160	250	480	280 (2-4-86)
Clark Fork at Drummond	4000	12331600	1967-68, 1972-83	2,378	9,600	13,000	20,000	20,000 (6-20-08)
Nevada Creek Near Finn	4800	12335500	1939-86	116	1,400	1,900	3,100	1,800 (5-22-81)

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PROBABLE MAXIMUM FLOOD DETERMINATION

The Probable Maximum Flood (PMF) values were calculated using the calibrated HEC-1 model of the Silver Bow Creek basin and procedures described in Hydrometeorological Report No. 43 (HMR 43), Probable Maximum Precipitation, Northwest States, U.S. Department of Commerce, National Weather Service, 1966 (Ref. 10) and Hydrometeorological Report No. 55A (HMR 55A), Probable Maximum Precipitation--United States Between the Continental Divide and the 103rd Meridian, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1988 (Ref. 11). Since the Silver Bow Creek watershed is bordered on three sides by the Continental Divide, both HMR 43 and HMR 55A were used to develop design precipitation for input to the model. This procedure provided a range in PMF flows.

HMR 43 PROCEDURES

Probable Maximum Precipitation (PMP) was determined for the general storm type for October through June and summer thunderstorms for May through September. Only the general storm PMP was used in the HEC-1 model since thunderstorm runoff for the area of Silver Bow Creek basin above the ponds would not be augmented by snowmelt during the summer months.

In determining the general storm PMP over the stream basin, two storm components were considered; orographic and convergence

precipitation. Orographic precipitation is defined as precipitation falling as a result of the lifting effect of a topographic feature, such as a mountain ridge, on a flow of air passing over it. Convergence precipitation includes all precipitation resulting from lifting induced by atmospheric processes other than orographic. These are mainly horizontal convergence, frontal lifting, and instability.

The distribution of the PMP was arranged in 1-hour increments following the procedure outlined in NOAA Atlas 2, Precipitation Frequency Atlas for the Western United States, Volume I (Montana) (Ref. 8).

HMR 55A PROCEDURES

Procedures outlined in the newly published HMR 55A were also followed to develop design probable maximum precipitation (PMP). Values for the 1-hour, 6-hour, 24-hour, and 72-hour maximum precipitation were taken directly from plates provided in the report. Using these values and considering basin size and location, the final precipitation amounts were obtained. These amounts were then arranged in 1-hour increments using the procedures outlined in NOAA Atlas 2 (Ref. 8) and input to the calibrated HEC-1 model.

Total storm amounts for the PMP using HMR 43 and HMR 55A were 12.00 inches and 19.44 inches, respectively, for a 72-hour period; and the maximum 1-hour values were 1.68 inches and

2.55 inches, respectively. It should be noted that during the development of the PMP, HMR 55A was being republished (June 1988). There were concerns with values obtained from the original HMR 55 so NOAA reanalyzed and subsequently changed and republished a new HMR 55A. There are now concerns with PMP values obtained using HMR 43. This report is now being revised by NOAA. Since these problems were noted, MDHES requested that procedures outlined in both reports be followed to develop the PMP which resulted in a range in flows for the PMF.

The PMP values computed according to Hydrometeorological Report No. 43 (Ref. 10) and 55A (Ref. 11) were compared to PMP values determined from procedures in the Design of Small Dams, U.S. Bureau of Reclamation, 1977 (Ref. 12). The PMP values computed using the Bureau of Reclamation guidelines were considerably lower and therefore were not used in the PMF HEC-1 model.

Although PMP was developed for the months of October through June, hydrologic factors indicated that only certain months would have the highest PMF.

WINTER PMF

The probability of frozen ground increases from December through February, with no historical flood events resulting from frozen ground in October, November, or after February. Snowmelt factors increase from December through spring, and snowcover increases from October through April. The combina-

tion of factors leading to a winter PMF involving frozen ground would generally occur in January and February.

Meteorological conditions for the winter PMF were developed for January and February. The meteorological data for air temperature, dew point, wind speed, and solar radiation data were distributed over the 72-hour PMP storm using the time distribution in Hydrometeorological Report No. 43 (Ref. 10). Meteorological factors causing the greatest snowmelt occur during hours 36 to 42, coincident with the greatest precipitation intensities. Areas of frozen ground were based on reasonable increases in the areas of frozen ground used in the January 1974 and February 1986 HEC-1 model flood simulations. Frozen ground was assumed to cover all basin area below 6,000 feet in elevation. An analysis of these historical events and snow cover observed at snow courses on February 1 and March 1 in the Silver Bow Creek basin was used to determine snow cover at elevations over 6,000 feet. Average snow depths for February 1 were sufficient to ensure that snowmelt zones produced runoff during the peak flow period of the January and February PMF.

SPRING PMF

The spring PMF is a rain-on-snow event which would occur in the months of March through June. After June, snowpacks cover only limited areas at higher elevations. Historically, all of the largest spring flood events occurred in May and June. Air

temperature, dew point, and solar radiation reach maximum values in June. In the most likely snowpack condition to occur with the PMF, the higher elevation snowpacks would not be saturated at the beginning of a storm until May. Warmer air temperatures causing rain and snowmelt at high elevations are not likely to occur until May when storm tracks bring air masses from the Gulf of California and the Gulf of Mexico. This combination of factors restricts the spring PMF to the months of May and June.

Meteorological conditions for the spring PMF were developed for May and June. The distribution for air temperatures, dew point, wind speed, and solar radiation for the 72-hour storm was developed using the procedure shown in the Hydrometeorological Report No. 43 (Ref. 10). Meteorological factors causing the greatest snowmelt occur in hours 36 to 42, coincident with the greatest precipitation. Snow cover for the May and June PMF was developed from an analysis of observed snow depths on April 1, May 1, and June 1 at snow courses and snow pillow sites in the Silver Bow Creek basin. For the PMF HEC-1 model, snow area and water content were set so that snowmelt would occur during the peak rainfall intensity increment. These values were similar to those used in the June 1908 HEC-1 simulation. Full snow cover was modeled for areas above 5,000 feet in elevation.

Other hydrological parameters used in the HEC-1 PMF simulations were set to values developed in the reconstitution of the historical June 1908, January 1974, June 1975, May 1981, and

February 1986 floods. These parameters included subbasin lag times, peaking factors, initial losses, infiltration rates, and channel routing coefficients.

The PMF hydrographs for Silver Bow Creek for the maximum runoff calculated at the ponds diversion structure, including flow from Mill and Willow Creeks, is shown in Figure 48 from procedures contained in HMR 43, and in Figure 49 from procedures contained in HMR 55A. The maximum PMF occurs in June with a peak of 128,000 cfs and a volume of 323,000 acre-feet using HMR 43 procedures, and 210,000 cfs with a volume of 467,000 acre-feet using HMR 55A procedures.

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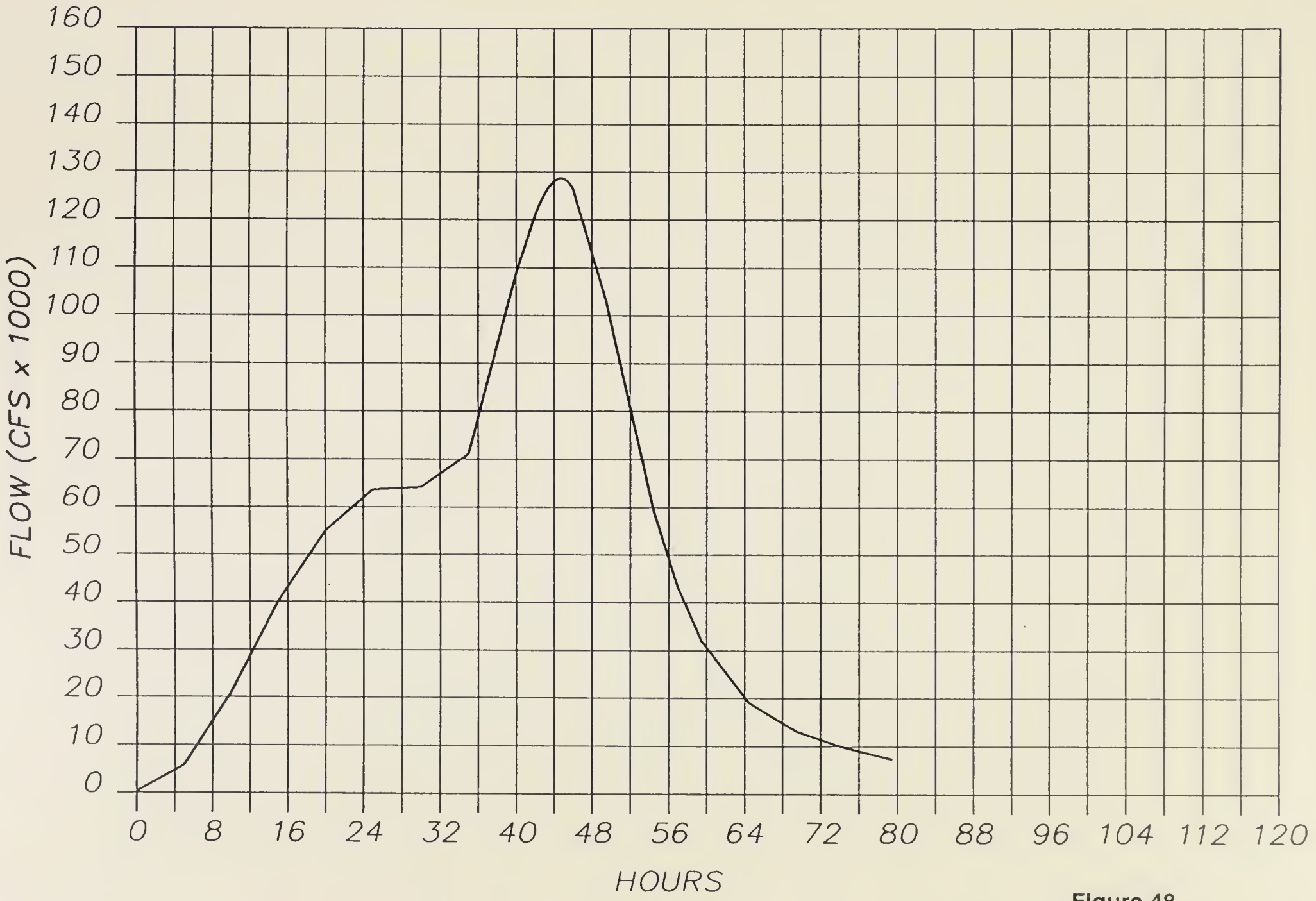

Figure 48
COMPUTED PROBABLE MAXIMUM FLOOD USING HMR 43 PROCEDURES; NODE 29; SILVER BOW CREEK BELOW MILL WILLOW AT PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

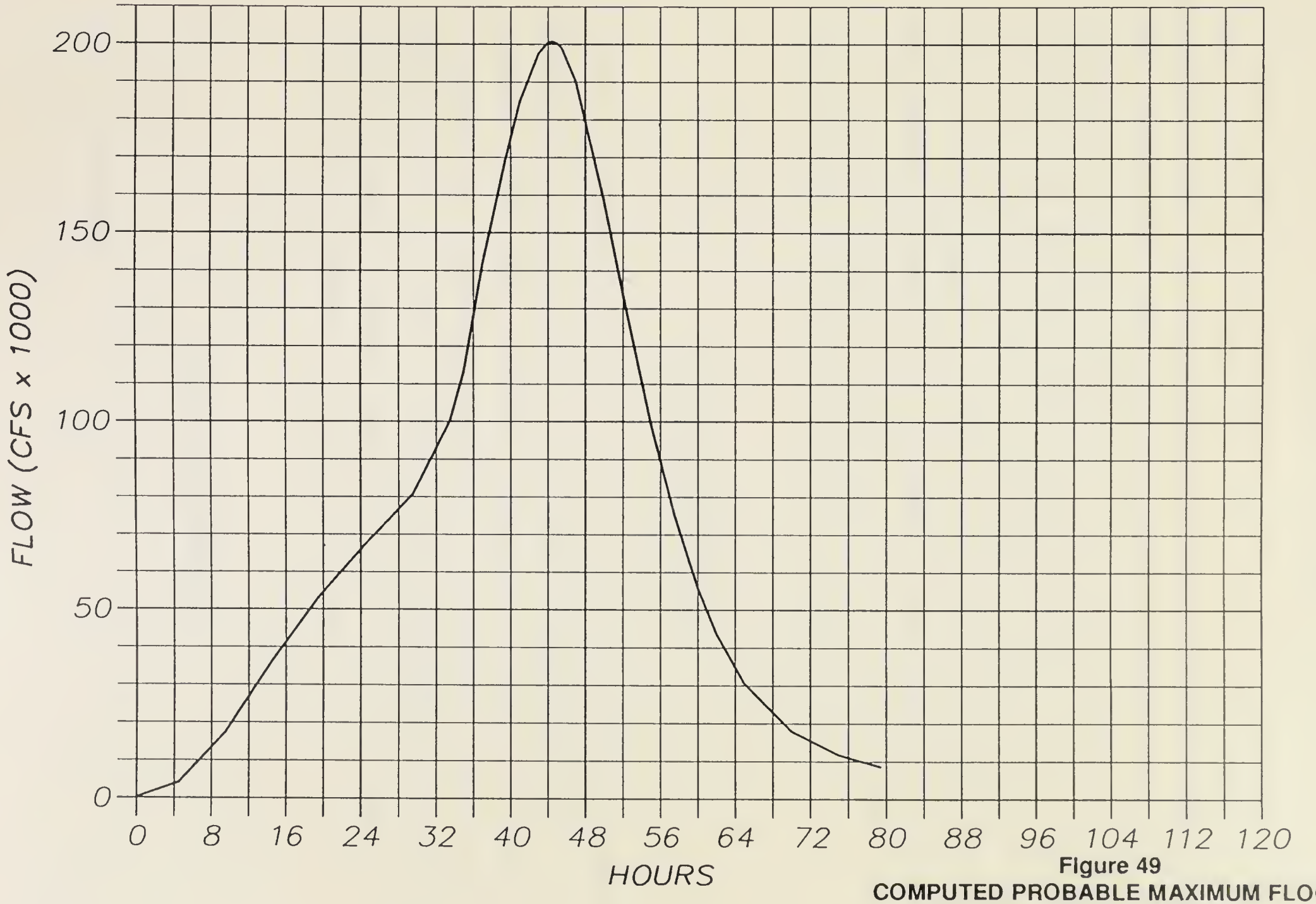

Figure 49
COMPUTED PROBABLE MAXIMUM FLOOD USING HMR 55A PROCEDURES; NODE 29; SILVER BOW CREEK BELOW MILL WILLOW AT PONDS DIVERSION
SILVER BOW CREEK FLOOD MODELING STUDY

HYDRAULIC ANALYSES

Analyses of the hydraulic characteristics of Silver Bow Creek were carried out to provide estimates of the water surface elevations of floods for the 10-, 25-, and 100-year recurrence intervals. To provide these estimates, water surface elevations were computed using the USCE HEC-2 standard-step-backwater computer program. Tasks required for providing data to this program included field reconnaissance, aerial photography, field surveys, mapping, digitizing of cross section data, and the previously documented hydrology analyses.

FIELD RECONNAISSANCE

A field reconnaissance of the study area was made to determine conditions along the flood plain (e.g., types and number of hydraulic structures involved, locations of cross sections to be surveyed); to provide estimates of roughness coefficients (Mannings "n" values); to provide photo documentation of field conditions; and to select locations where sediment samples were needed for the sediment transport analyses.

AERIAL PHOTOGRAPHY

Aerial photography of the Silver Bow Creek study area was collected on October 20, 1987, at a scale of 1:14400. Standard

photogrammetric methods were used to provide the information needed to prepare the required models (cross sectional data and topographic contours of the flood plain). Other secondary benefits of the aerial photography task included: updating of base map features, estimation of Mannings roughness coefficients, identification of hydraulic control structures, and selection of cross section locations.

The aerial photography was conducted while the sun angle was above 30 degrees and the water courses were in the main channels. The products were suitable for use in the stereoplotting instruments. Accuracy requirements for the photography for determining spot elevations of ground points are that 90 percent of all spot elevations placed on the maps have an accuracy of at least ±1 foot, and the remaining 10 percent not be in error by more than ±2 feet.

FIELD SURVEYS

Field surveys of Silver Bow Creek were conducted to obtain field checks for channel and flood plain cross sections; to identify or establish necessary elevation reference marks (ERMs); and to obtain the physical dimensions of all hydraulic structures. Third-order leveling was used to tie temporary benchmarks and ERMs to the National Geodetic Vertical Datum of 1929 (NGVD); to determine the elevation of any known high-water marks; to measure all hydraulic control structures; and, where

needed, to establish vertical and horizontal control for aerial photogrammetry and digitizing.

VERTICAL CONTROL

The field surveys were performed to obtain vertical photogrammetric control, with all elevations referred to NGVD. Vertical control points for stereomodels that were established by other than third-order procedures have elevations that are accurate to within ±0.4 foot. These control points were determined from benchmarks of third-order accuracy.

HORIZONTAL CONTROL

Each horizontal control point surveyed was plotted on the map, with the coordinate grid in which it should lie, to an accuracy of 0.01 inch of its true position as expressed by the plane coordinates computed for the point. Any non-coordinate control procedures that were utilized have the same accuracy as that for control point plotting.

MAPPING

Topographic maps of the Silver Bow Creek floodplain area were developed using the aerial photography and field surveys for horizontal and vertical control. Maps at a scale of 1:2400 with 4-foot contours and intermediate 2-foot contours were prepared, using standard photogrammetric procedures, for the

main channel and estimated 100-year floodplain area along Silver Bow Creek.

PLANIMETRIC FEATURES

Needed planimetric features that were well defined on the photographs were plotted so that their positions on the maps were accurate to within at least 0.025 inch of their true coordinate position. None of the features were misplaced on the maps by more than 0.05 inch from their true coordinate position.

ANALYTICAL CONTROL

The maximum number of stereomodels used in photogrammetric bridging was 4 for vertical control and 10 for horizontal control. The root-mean-square error for aerial analytical triangulation was 1:8000 absolute error as a fraction of flight height with horizontal and vertical points.

DIGITIZING

Cross sections of the main channel and floodplain areas used in the hydraulic analyses (HEC-2) were digitized using the 1:14400 aerial photographs obtained on October 20, 1987, with the field-surveyed horizontal and vertical control. Cross sections were located at close intervals above and below all hydraulic structures to compute the significant backwater from these

structures. Locations of these cross sections are shown on the 100-year flooded area maps (Appendix A) and the flood profiles (Appendix B).

HEC-2 MODEL CONSTRUCTION

A hydraulic model of Silver Bow Creek was prepared to provide estimates of water surface elevations during the 10-, 25-, and 100-year floods. The USCE HEC-2 standard-step-backwater computer program was used to compute the water surface elevations and other hydraulic parameters needed to estimate the water surface profiles and related flooded areas. The model incorporates the following data:

- Digitized data defining cross sections in the Silver Bow Creek channel and floodplain; cross sections were located at approximately 750-foot intervals and were perpendicular to the direction of flow

- Instantaneous peak discharge data obtained from the hydrologic analyses for the 10-, 25-, and 100-year flood events (calculated by the HEC-1 computer program)

- Field and digitized data defining the geometry of the waterway above and beneath each bridge crossing Silver Bow Creek

- Loss coefficients needed to evaluate backwater caused by friction, expansion and contraction, and bridge backwater related to pier configuration, roadway shape, and pressure and weir flow

- Channel and overbank flow distances between digitized cross sections

Hydraulic modeling was performed on approximately 30 miles of Silver Bow Creek, beginning near the Berkeley pit and extending downstream to a point near the confluence of Silver Bow Creek and Warm Springs Creek where the Clark Fork River begins. Originally the study reach for backwater analyses began at the upstream area of Pond 3. The Mill-Willow bypass reach was added to the study at a later date. The model was divided into 11 reaches to simplify calibration because of the length of the stream channel being modeled.

The HEC-2 program was used to calculate the approximate water surface elevations at each cross section and to generate the water surface profiles for each flood (Appendix B). Flood boundary maps were prepared using the calculated elevations to show the 100-year flood limits (Appendix A). The locations of the cross sections used to define the channel and overbank geometry are also shown in Appendixes A and B. Flooded area maps are shown for the entire study reach from the confluence of Silver Bow Creek (Mill-Willow bypass) with Warm Springs Creek, while flood profiles are only shown from Pond 3 upstream to Butte.

The data required to define the elevation and geometry of all hydraulic structures on Silver Bow Creek were obtained during field surveys. Channel roughness coefficients (Mannings "n") required for hydraulic calculations were estimated during field inspection of the floodplains. Roughness coefficient values varied according to the roughness of the streambed and overbanks and ranged from 0.045 to 0.055 for the main channel, and from 0.075 to 0.150 for the overbanks.

The values of contraction and expansion loss coefficients used to calculate energy losses due to changes in the channel cross section within a reach were 0.3 and 0.5, respectively, for the main channel. These coefficients were increased to 0.5 and 0.8, respectively, at bridges and culverts. Bridge loss coefficients varied according to pier configuration, weir shape, and condition of flow (pressure or weir).

The 11 reaches used to model Silver Bow Creek were divided such that the beginning cross section of each reach was the same as the ending cross section of the previous reach. The starting water surface elevations for the first reach, near the confluence of Silver Bow Creek and Warm Springs Creek, were determined using normal depth calculations. The starting water surface elevations for subsequent reaches were the end conditions of the previous reach.

Only cross sections in the Silver Bow Creek flood plain were modeled in this study. However, it is important to note that from Section 90, just upstream of where Silver Bow Creek

crosses Interstate 90, to Section 170, just upstream of Stewart Street near Opportunity, the cross sections and flows of Silver Bow Creek, Mill Creek, and Willow Creek were combined for the 25- and 100-year floods. This was done because the floodwaters for these events mix and flow together within the same floodplain.

The hydraulic analyses for this study were based only on the effects of unobstructed flow. The calculated water surface elevations, as shown on the profiles, are considered valid only if bridges and culverts remain unobstructed and do not fail.

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SEDIMENT TRANSPORT MODELING

Several bedload transport models have been developed to predict sediment transport and erosion in streams. The best known and most popular models are the U.S. Army Corps of Engineers' HEC-6 model and Dr. Howard Chang's FLUVIAL-12 river hydraulics model. Both models are capable of calculating scour and sediment transport quantities; however, only FLUVIAL-12 is capable of calculating bank erosion due to river widening during floods. Since bank erosion is the primary source of sediment transport in Silver Bow Creek, FLUVIAL-12 was selected for the sediment transport modeling.

Sediment samples were taken throughout the study reach in the fall of 1987 at the locations shown in Figure 50. Gradation analyses were conducted on the collected materials so that the size fractions of the Silver Bow Creek sediment could be input to the transport model. Flow data and cross section information needed for the sediment analyses were taken from the previously mentioned hydrologic and hydraulic analyses.

FLUVIAL-12

The FLUVIAL-12 model was developed to simulate the combined effects of flow hydraulics, sediment transport, and channel changes for a given series of flows. The model is unique in that the cross section geometry is allowed to change as a

Figure 50
SEDIMENT SAMPLE SITES AND POTENTIAL RESERVOIR SITES
SILVER BOW CREEK FLOOD MODELING STUDY

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function of time, flowrate, and other hydraulic and bed material characteristics. Although other models that represent changes in cross section geometry have been developed, FLUVIAL-12 is the only model that represents these changes through a variable hydrograph and through a reach with varying bed materials. FLUVIAL-12 has been selected for numerous sediment transport and alluvial river mechanics studies in recent years.

FLUVIAL-12 operates by iterating through timesteps and solving numerous hydraulic, energy, and mass balance equations. At the end of each timestep, new hydraulic, bedload material, and cross section data are stored. The model proceeds to the next timestep using the data calculated in the previous timestep. By operating in this manner, the model is capable of simulating the variations in hydraulics, bed materials, and cross section geometry over time.

As with most models, certain assumptions must be made within the model to solve the algorithms. FLUVIAL-12 assumes that the cross sections at each end of the reach being modeled are fixed. For this study, a number of subreaches were modeled. The ends of each subreach were overlapped to minimize the effects of the model's assumption of fixed end cross sections. FLUVIAL-12 also assumes that the stream is carrying the maximum possible bedload (for the hydraulic and bedload material conditions at the time increment) at the upstream cross section. This assumption is reasonable for Silver Bow Creek because there is an ample supply of bedload materials available at the high flows modeled.

STUDY METHODS

The study reach was separated into 13 subreaches for modeling because of characteristics of the study reach and the voluminous quantity of cross section data. Sediment transport and erosion were modeled in each subreach for a 10-, 25-, and 100-year recurrence flood event. Bank material distribution analyses from the end of each subreach were used to describe the available erodible material for each subreach. Yang's stream power equation was used in the FLUVIAL-12 model to estimate sediment transport rates.

MODEL PREDICTIONS

The model predicted that approximately 100,000 cubic yards of sediment would reach the ponds during the 100-year hydrograph. For the 25- and 10-year hydrographs, approximately 50,000 and 25,000 cubic yards of sediment, respectively, would reach the ponds. Erosion, deposition, and sediment transport were especially high in the reach immediately upstream of the ponds.

Figures 51 through 55 present the estimated changes in cross section geometry during the peak of the 100-year flood as calculated by the FLUVIAL-12 computer program.

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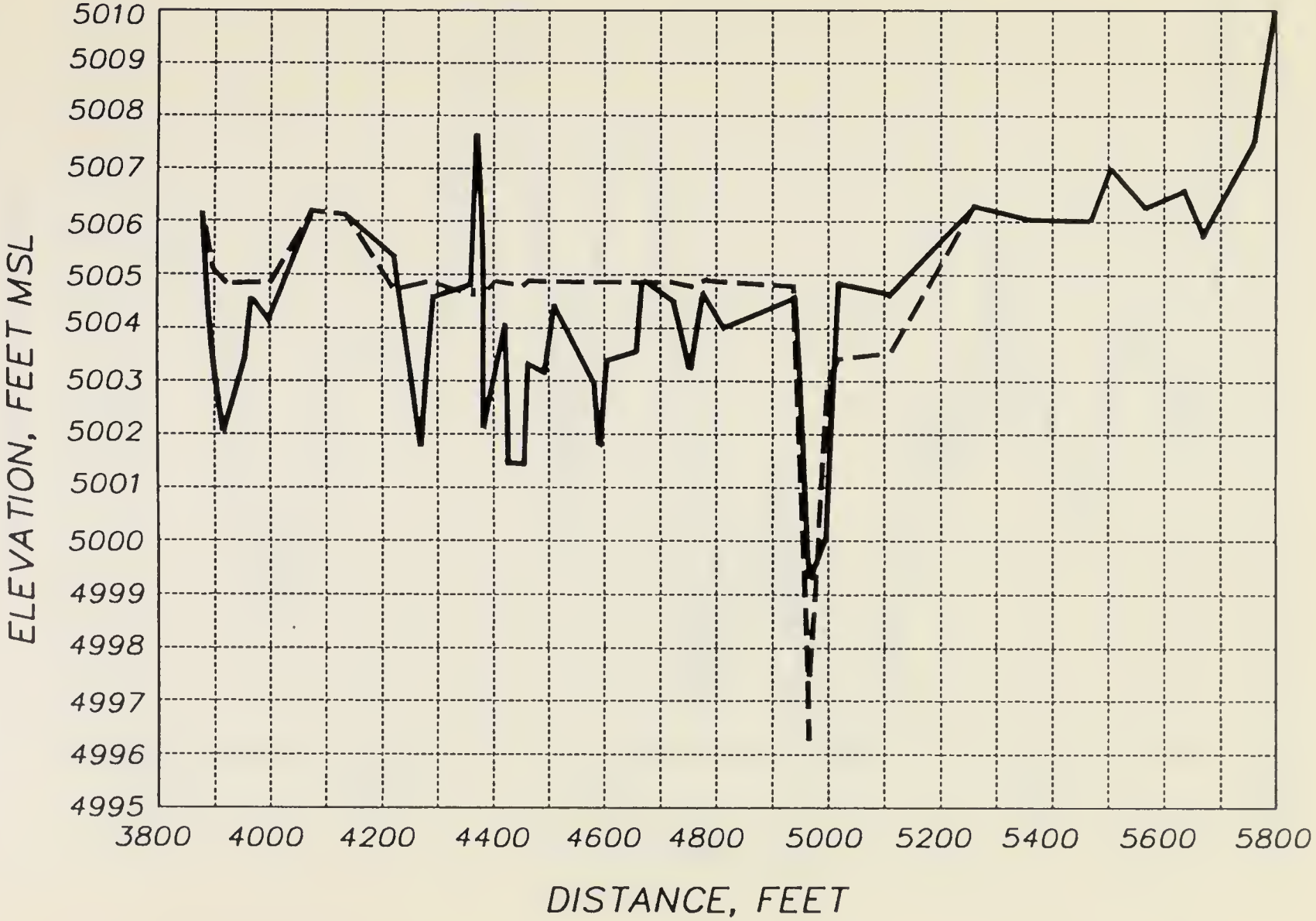
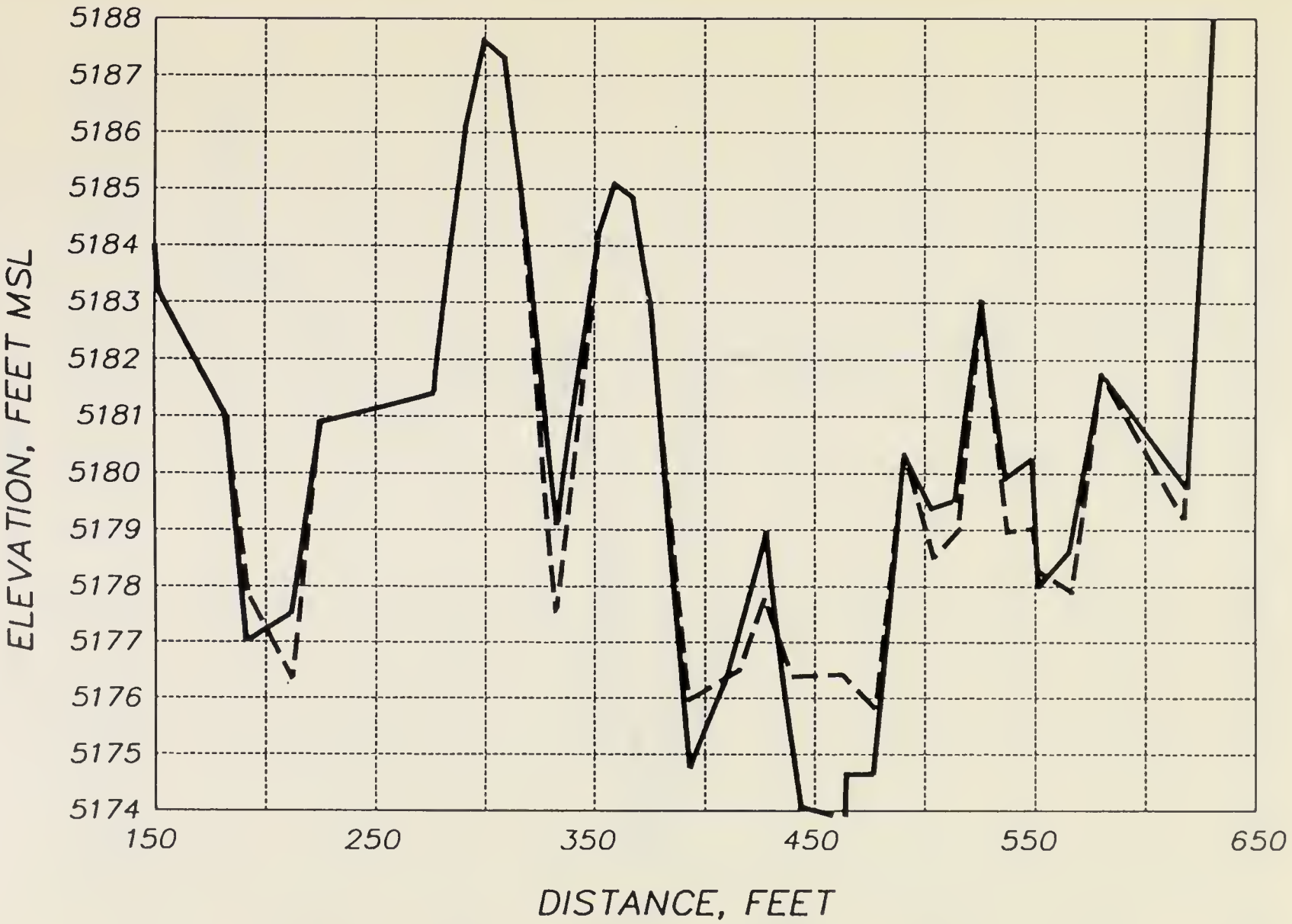


——— INITIAL CROSS SECTION

– – – – CROSS SECTION AT PEAK 100-YEAR FLOW

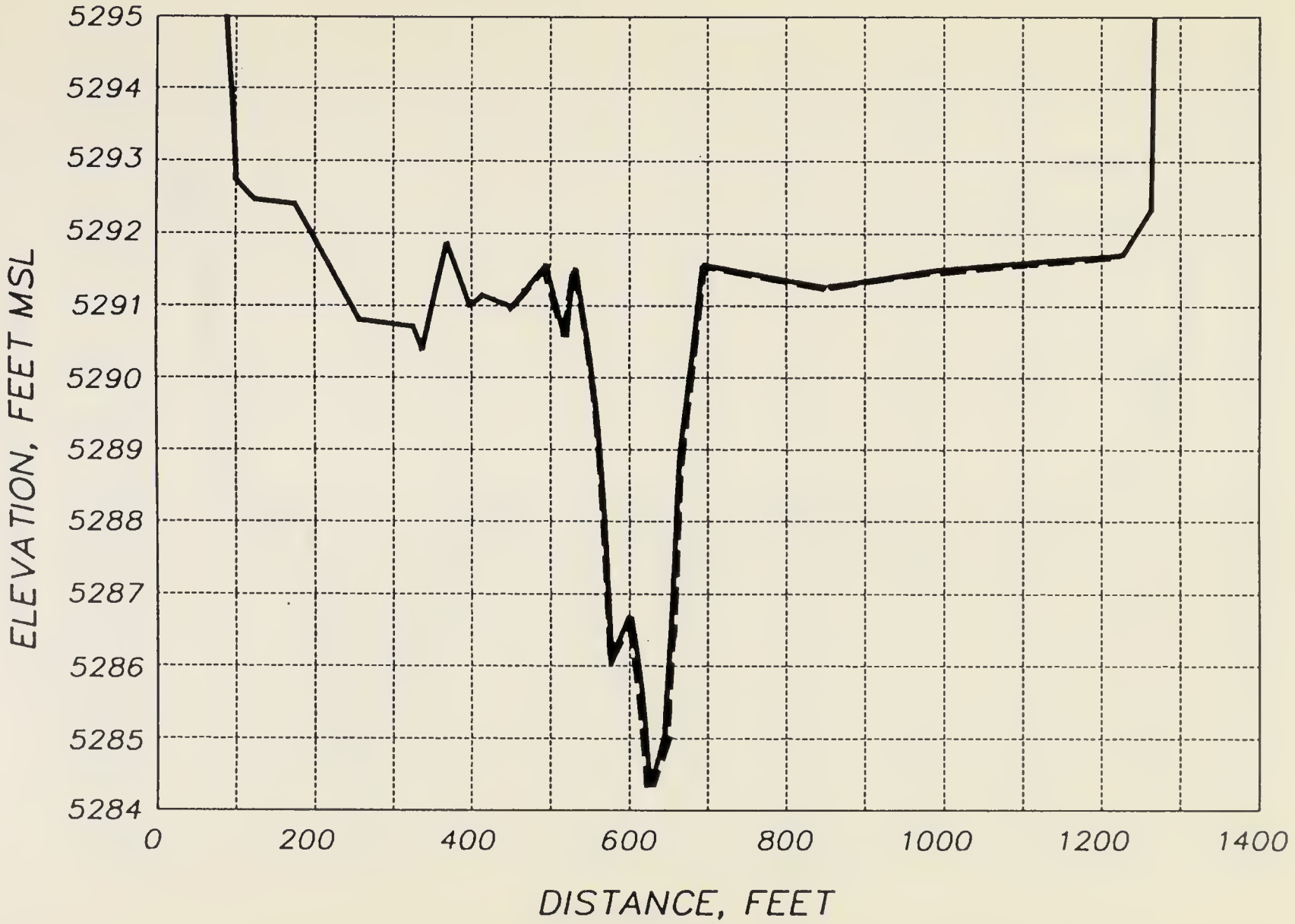
Figure 51
SEDIMENT TRANSPORT MODELING
CROSS SECTION CHANGES,
CROSS SECTION 300
SILVER BOW CREEK FLOOD MODELING STUDY



INITIAL CROSS SECTION

CROSS SECTION AT PEAK 100-YEAR FLOW

Figure 52
SEDIMENT TRANSPORT MODELING
CROSS SECTION CHANGES,
CROSS SECTION 690
SILVER BOW CREEK FLOOD MODELING STUDY



INITIAL CROSS SECTION

CROSS SECTION AT PEAK 100-YEAR FLOW

Figure 53
SEDIMENT TRANSPORT MODELING
CROSS SECTION CHANGES,
CROSS SECTION 1210
SILVER BOW CREEK FLOOD MODELING STUDY

INITIAL CROSS SECTION

CROSS SECTION AT PEAK 100-YEAR FLOW

Figure 54
SEDIMENT TRANSPORT MODELING
CROSS SECTION CHANGES,
CROSS SECTION 1770
SILVER BOW CREEK FLOOD MODELING STUDY

——— *INITIAL CROSS SECTION*

NOTE: *NO CHANGES OCCURRED DURING PEAK 100-YEAR FLOW.*

Figure 55
SEDIMENT TRANSPORT MODELING CROSS SECTION CHANGES, CROSS SECTION 2070
SILVER BOW CREEK FLOOD MODELING STUDY

IDENTIFICATION OF POTENTIAL RESERVOIR SITES

Potential reservoir sites on Silver Bow Creek and its tributaries were identified for possible future impoundment of flood flows. These reservoir sites were intended strictly for flood control to store flows up to 100-year flood, thus reducing peak flows in Silver Bow Creek. The dams would not normally store water but would capture and regulate high flows to help mitigate possible downstream contamination.

The potential reservoir site locations are shown on Figure 50 and are described in the following subsections.

SILVER BOW CREEK--SITES A AND B

Silver Bow Creek generally flows in a broad basin without a suitable location for stream impoundment. However, the creek flows through a narrow canyon near Durant where two potential reservoir sites were identified; one site just upstream of the confluence with German Gulch, and one just downstream of German Gulch. Both sites are located in a relatively narrow canyon with steep rock abutments. For flood storage purposes a dam height of 100 to 200 feet could be used.

Both of these sites would require relocation of two railroad lines and an electrical transmission line.

BROWNS GULCH--SITES C, D, E, F

Browns Gulch contains several potential reservoir sites; flows could be contained in several small reservoirs or one large reservoir. Eighty-to-150-foot-high dams would be feasible with Site D requiring the relocation of a pipeline and road. Site E would capture the significant drainages of Browns Gulch while Site D would capture all of the drainage except for Bull Run Creek.

FLINT CREEK, PERDEE CREEK, HOMESTEAD CREEK, AND WHITECRAFT GULCH--SITES G, H, I, J

Small 60- to 80-foot-high dams appear feasible on these four drainages. The reservoirs would have relatively small storage capacity because of the steep stream gradient and narrow canyons.

GERMAN GULCH--SITES K, L, M, N

Flooding at German Gulch could be contained by either a series of small 80- to 100-foot-high dams located on Notan Creek, Beefstraight Creek, and German Gulch, or one large 100- to 200-foot-high dam located on German Gulch below the confluence of the above creeks. The canyons are relatively steep with rock exposed in most of the abutment areas.

BOIT642/025.50/jms

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Appendix A
100-YEAR FLOOD BOUNDARY MAPS

10 OVERSIZE MAPS--PROVIDED IN PLASTIC POCKETS

SCALE: 1"=500'

D (80) CROSS SECTION LOCATION

WARM SPRINGS TREATMENT POND 1

WARM SPRINGS TREATMENT POND 2

WILDLIFE POND

WARM SPRINGS TREATMENT POND 3

STUDY LIMITS

POND 2 DISCHARGE

WILDLIFE POND

SEWAGE LAGOONS

100-YEAR FLOOD LIMITS

MILL-WILLOW BYPASS

I-90

WARM SPRINGS CREEK

RAILROAD

MONTANA HIGHWAY 48

MATCHLINE A SEE SHEET 2

NOTE THE LIMITS OF FLOODING FROM WARM SPRINGS CREEK WERE NOT STUDIED.

CH2M HILL

DSGN JB
DR JB
CHK Um
APVO

NO	DATE	REVISION	BY	APVO

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SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 1 OF 10

DATE 6-1-88

PROJ NO B0120840.S3

SCALE 1"=500'

D (80) CROSS SECTION LOCATION

WARM SPRINGS TREATMENT POND 3

DIVERSION STRUCTURE

100-YEAR FLOOD LIMITS

MILL-WILLOW BYPASS

I-90

RAILROAD

SILVERBOW CREEK

MILL CREEK

MATCHLINE A SEE SHEET 1

MATCHLINE B SEE SHEET 3

NOTE: THE LIMITS OF FLOODING FROM MILL CREEK WERE NOT STUDIED.

TAILINGS POND

DSGN		NO	DATE	REVISION	BY	APVD	
DR							
CHK							
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SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 2 OF 10

DATE 6-1-88

PROJ NO B0120840.S3

SCALE 1"=500'

D (80) CROSS SECTION LOCATION

I-90

RAILROAD

SILVERBOW CREEK

MATCHLINE B SEE SHEET 2

MATCHLINE C SEE SHEET 4

MILL CREEK

100-YEAR FLOOD LIMITS

US 10A

WILLOW CREEK

STUDY LIMITS

NOTE: THE LIMITS OF FLOODING FROM WILLOW CREEK WERE NOT STUDIED.

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CHK

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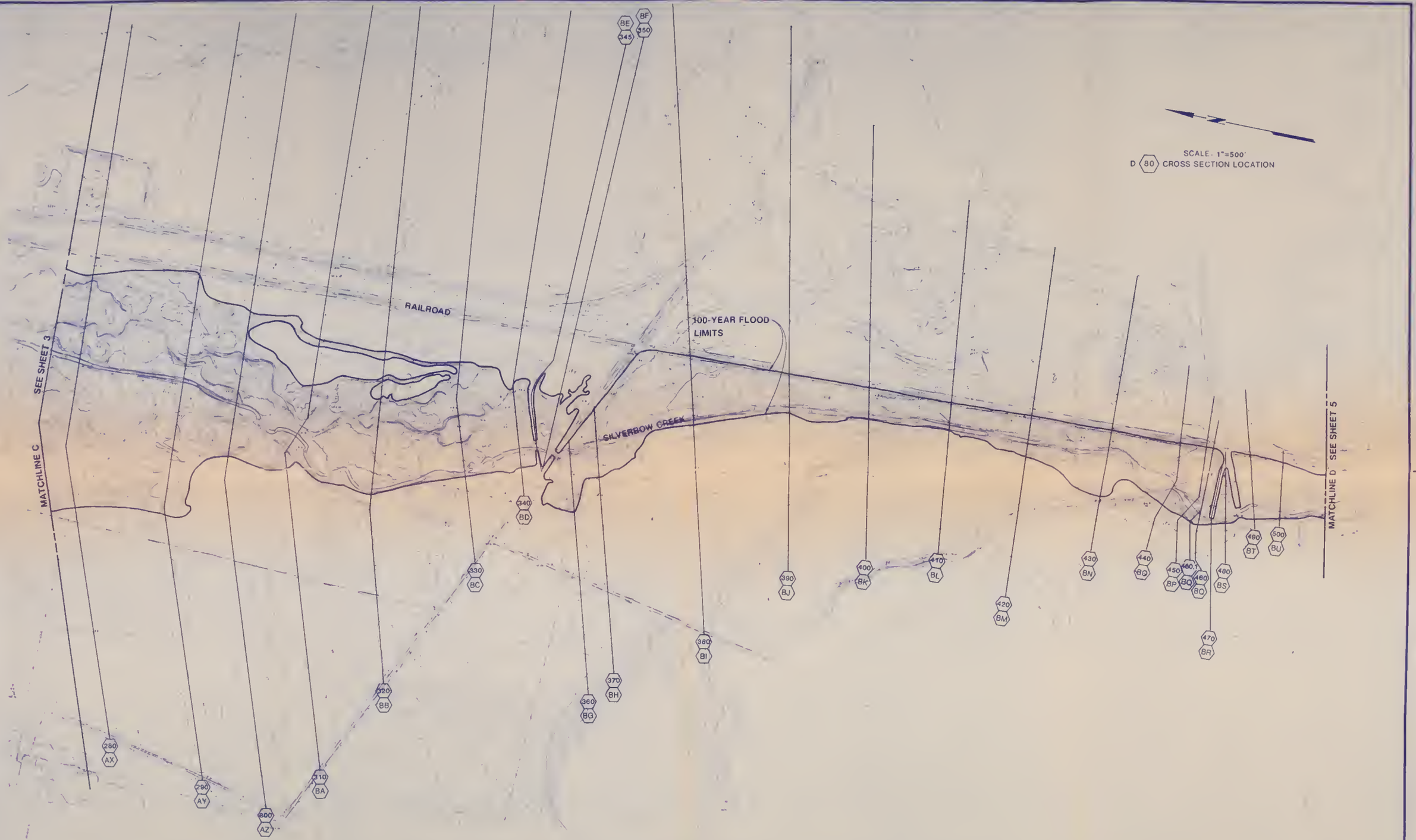
SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 3 OF 10

DATE 6-1-88

PROJ NO 80120840.S3



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SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 4 OF 10
DATE 6-1-86
PROJ NO 80120840.53

SCALE: 1"=500'

D (80) CROSS SECTION LOCATION

NOTE: THE LIMITS OF FLOODING FROM GERMAN GULCH WERE NOT STUDIED.

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DR GB
CHK
APVD

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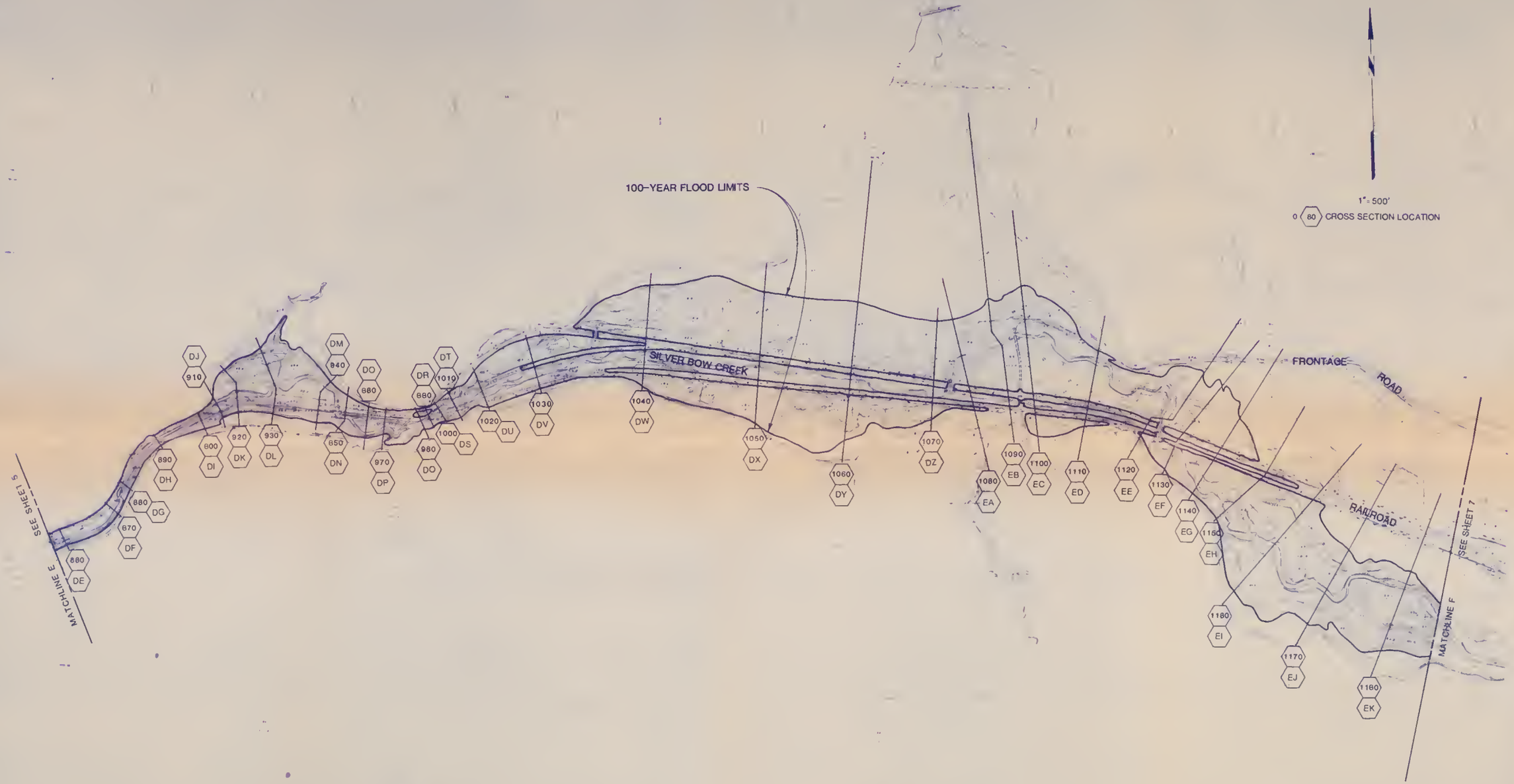
SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 5 OF 10
DATE 6-1-88
PROJ NO. 80120840.S3



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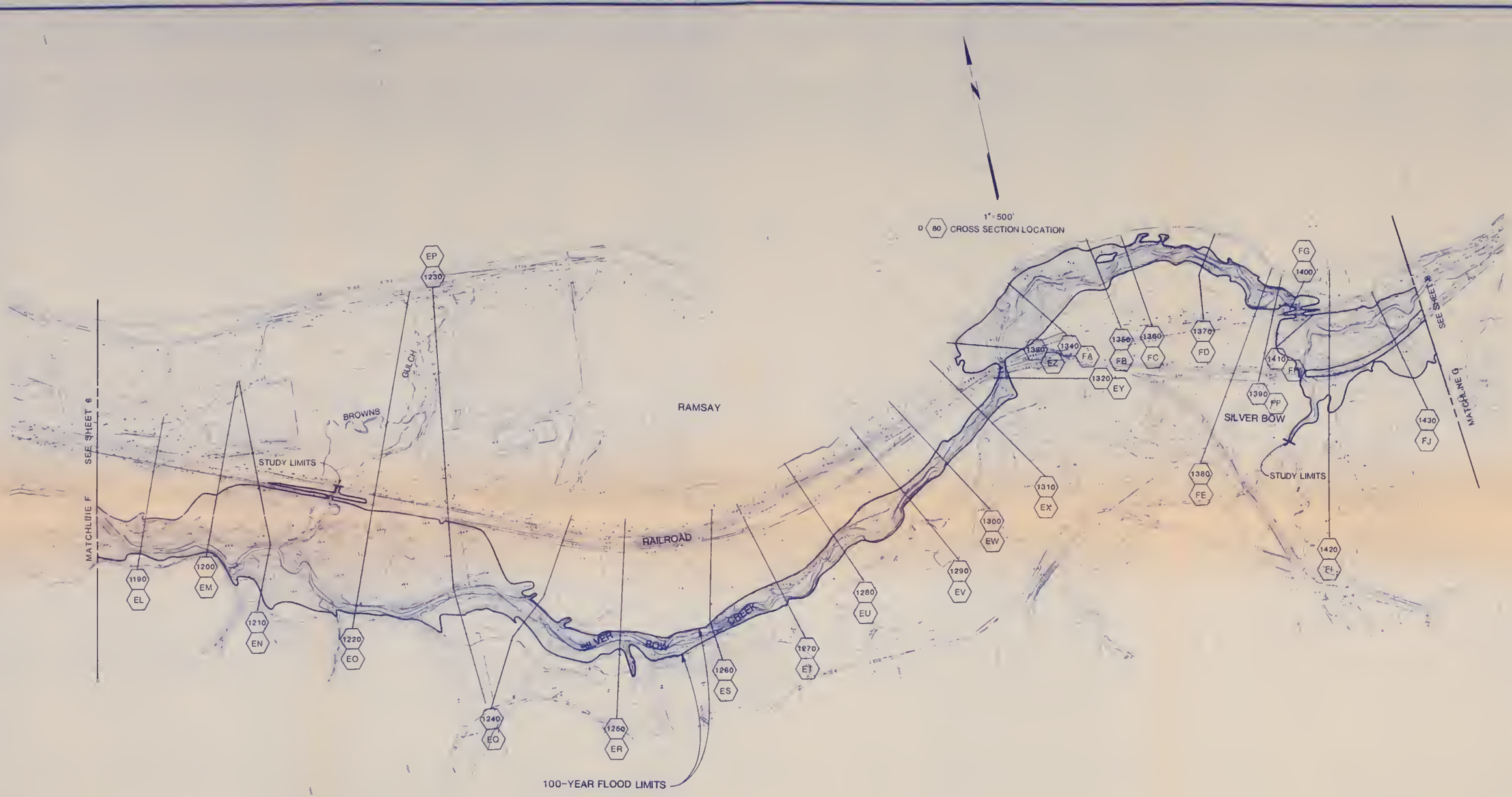
100-YEAR FLOOD BOUNDARY MAP

SHEET 6 OF 10
DATE 6-1-88
PROJ NO 80120840.S3



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	DR						SHEET 7 OF 10
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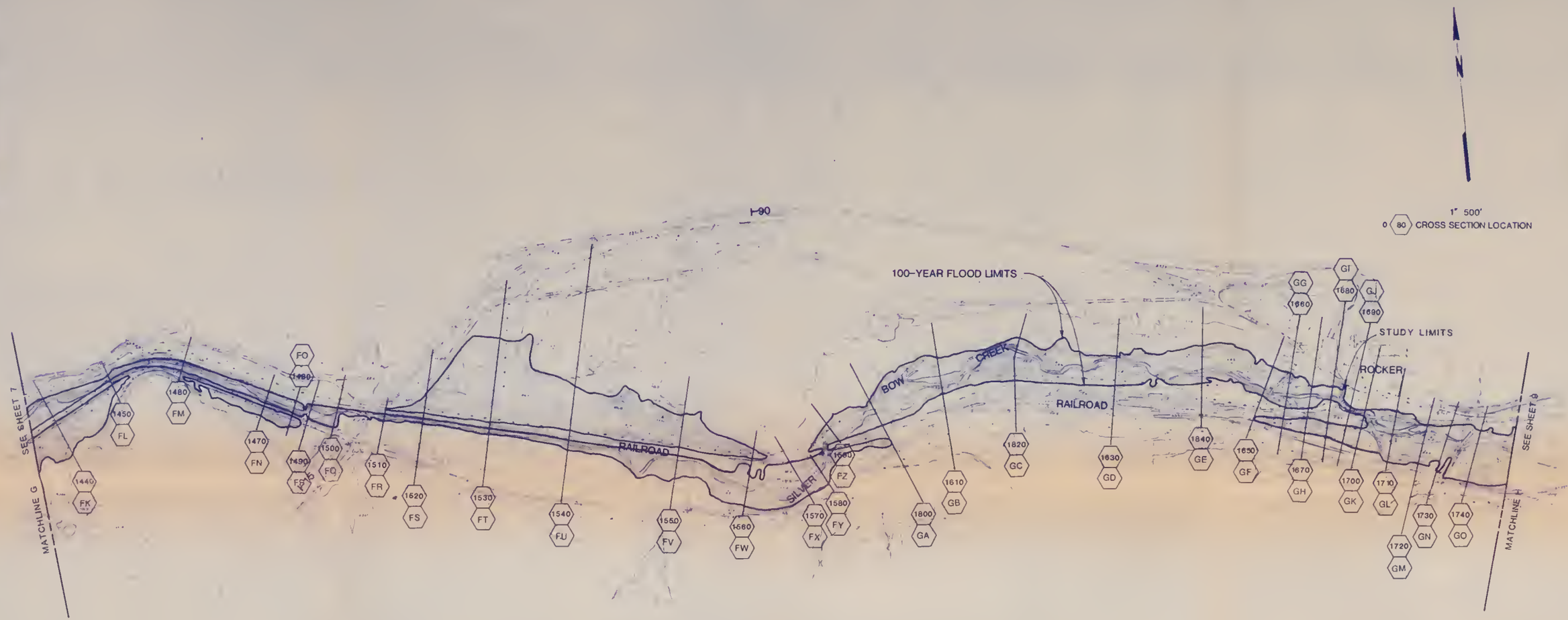

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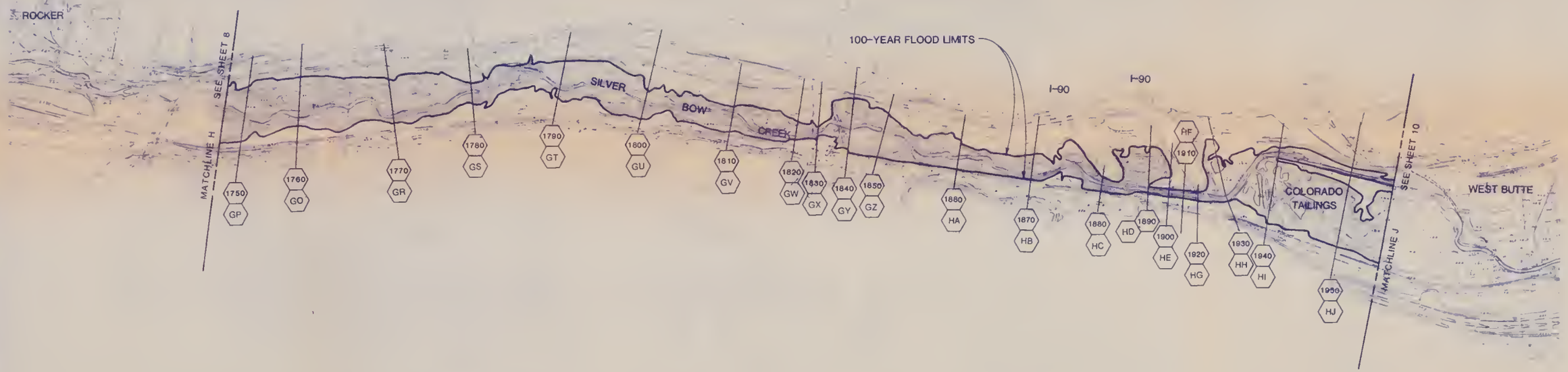
SILVER BOW CREEK FLOOD MODELING
100-YEAR FLOOD BOUNDARY MAP

SHEET 8 OF 10
DATE 6-1-86
PROJ NO 80120840.S3

1" = 500'

D (80) CROSS SECTION LOCATION



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	CHK									
	APVD									

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	DR						SHEET 10 OF 10
	CHK						DATE 6-1-88
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Appendix B
FLOOD PROFILES

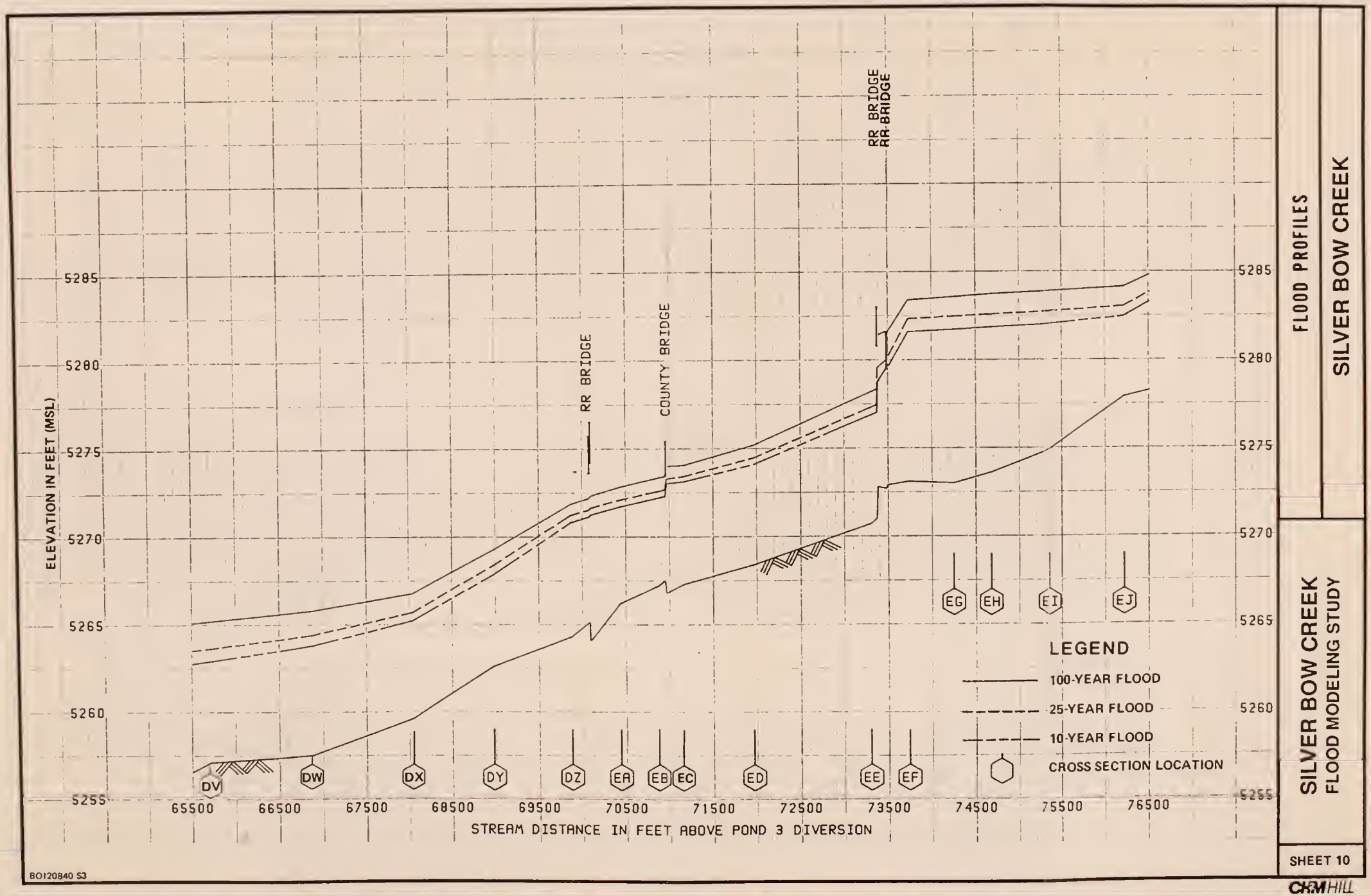
APPENDIX B
CROSS SECTION IDENTIFICATION

Cross Section Cross Reference - The listed cross sections are located on the 100-year flood boundary maps (Appendix A), and also on the flood profiles (Appendix B).

CROSS SECTION	HEC-2 CROSS SECTION	DISTANCE UPSTREAM OF POND 3 DIVERSION (feet)	CROSS SECTION	HEC-2 CROSS SECTION	DISTANCE UPSTREAM OF POND 3 DIVERSION (feet)
AA	50.00	295.00	CA	560.00	44124.00
AB	60.00	845.00	CB	570.00	44654.00
AC	70.00	1175.00	CC	580.00	44894.00
AD	80.00	1815.00	CD	590.00	45049.00
AE	90.00	2490.00	CE	600.00	45389.00
AF	100.00	3220.00	CF	610.00	45719.00
AG	110.00	4190.00	CG	620.00	45969.00
AH	120.00	6240.00	CH	630.00	46424.00
AI	130.00	8130.00	CI	640.00	46844.00
AJ	140.00	9720.00	CJ	650.00	47324.00
AK	150.00	11050.00	CK	660.00	48074.00
AL	160.00	11445.00	CL	670.00	48894.00
AM	170.00	12805.00	CM	680.00	49799.00
AN	180.00	13955.00	CN	690.00	50569.00
AO	190.00	15415.00	CO	700.00	51334.00
AP	200.00	16535.00	CP	710.00	52174.00
AQ	210.00	16810.00	CQ	720.00	53074.00
AR	220.00	17890.00	CR	730.00	54054.00
AS	230.00	18690.00	CS	740.00	54444.00
AT	240.00	20050.00	CT	750.00	54654.00
AU	250.00	21170.00	CU	760.00	54874.00
AV	260.00	22555.00	CV	770.00	55154.00
AW	270.00	23390.00	CW	780.00	55654.00
AX	280.00	24020.00	CX	790.00	56064.00
AY	290.00	25220.00	CY	800.00	56544.00
AZ	300.00	25865.00	CZ	810.00	57164.00
BA	310.00	26695.00	DA	820.00	57984.00
BB	320.00	27920.00	DB	830.00	58564.00
BC	330.00	28980.00	DC	840.00	58854.00
BD	340.00	29665.00	DD	850.00	59109.00
BE	345.00	29855.00	DE	860.00	59544.00
BF	350.00	29965.00	DF	870.00	60154.00
BG	360.00	30245.00	DG	880.00	60474.00
BH	370.00	30565.00	DH	890.00	61059.00
BI	380.00	31660.00	DI	900.00	61539.00
BJ	390.00	32720.00	DJ	910.00	61789.00
BK	400.00	33590.00	DK	920.00	62019.00
BL	410.00	34485.00	DL	930.00	62469.00
BM	420.00	35335.00	DM	940.00	63084.00
BN	430.00	36315.00	DN	950.00	63494.00
BO	440.00	37215.00	DO	960.00	63769.00
BP	450.00	37515.00	DP	970.00	63959.00
BQ	460.10	37609.00	DQ	980.00	64429.00
BR	470.00	37844.00	DR	990.00	64519.00
BS	480.00	38004.00	DS	1000.00	64649.00
BT	490.00	38369.00	DT	1010.00	64819.00
BU	500.00	38689.00	DU	1020.00	65129.00
BV	510.00	39489.00	DV	1030.00	65699.00
BW	520.00	40189.00	DW	1040.00	66859.00
BX	530.00	40974.00	DX	1050.00	68029.00
BY	540.00	42044.00	DY	1060.00	68964.00
BZ	550.00	43184.00	DZ	1070.00	69864.00

CROSS SECTION	HEC-2 CROSS SECTION	DISTANCE UPSTREAM OF POND 3 DIVERSION (feet)	CROSS SECTION	HEC-2 CROSS SECTION	DISTANCE UPSTREAM OF POND 3 DIVERSION (feet)
EA	1080.00	70424.00	GA	1600.00	104769.00
EB	1090.00	70854.00	GB	1610.00	105589.00
EC	1100.00	71154.00	GC	1620.00	106439.00
ED	1110.00	71954.00	GD	1630.00	107559.00
EE	1120.00	73284.00	GE	1640.00	108449.00
EF	1130.00	73719.00	GF	1650.00	109089.00
EG	1140.00	74229.00	GG	1660.00	109319.00
EH	1150.00	74659.00	GH	1670.00	109549.00
EI	1160.00	75339.00	GI	1680.00	109764.00
EJ	1170.00	76199.00	GJ	1690.00	109979.00
EK	1180.00	77189.00	GK	1700.00	110119.00
EL	1190.00	78264.00	GL	1710.00	110509.50
EM	1200.00	78984.00	GM	1720.00	110859.50
EN	1210.00	79744.00	GN	1730.00	111074.50
EO	1220.00	81064.00	GO	1740.00	111420.00
EP	1230.00	82124.00	GP	1750.00	111990.00
EQ	1240.00	83004.00	GQ	1760.00	112580.00
ER	1250.00	84084.00	GR	1770.00	113600.00
ES	1260.00	85104.00	GS	1780.00	114440.00
ET	1270.00	85954.00	GT	1790.00	115425.00
EU	1280.00	86814.00	GU	1800.00	116315.00
EV	1290.00	87834.00	GV	1810.00	117230.00
EW	1300.00	88369.00	GW	1820.00	117905.00
EX	1310.00	88984.00	GX	1830.00	118125.00
EY	1320.00	89464.00	GY	1840.00	118475.00
EZ	1330.00	89804.00	GZ	1850.00	118815.00
FA	1340.00	90404.00	HA	1860.00	119650.00
FB	1350.00	91319.00	HB	1870.00	120405.00
FC	1360.00	91729.00	HC	1880.00	121165.00
FD	1370.00	92549.00	HD	1890.00	121633.00
FE	1380.00	93249.00	HE	1900.00	121833.00
FF	1390.00	93389.00	HF	1910.00	121973.00
FG	1400.00	93597.00	HG	1920.00	122118.00
FH	1410.00	93879.00	HH	1930.00	122418.00
FI	1420.00	94179.00	HI	1940.00	123108.00
FJ	1430.00	94799.00	HJ	1950.00	123828.00
FK	1440.00	95529.00	HK	1960.00	124453.00
FL	1450.00	96279.00	HL	1970.00	125488.00
FM	1460.00	97034.00	HM	1980.00	125818.00
FN	1470.00	97944.00	HN	1990.00	126118.00
FO	1480.00	98229.00	HO	2000.00	126558.00
FP	1490.00	98429.00	HP	2010.00	126863.00
FQ	1500.00	98709.00	HQ	2020.00	127053.00
FR	1510.00	99189.00	HR	2030.00	127278.00
FS	1520.00	99589.00	HS	2040.00	127648.00
FT	1530.00	100239.00	HT	2050.00	128148.00
FU	1540.00	101019.00	HU	2060.00	128398.00
FV	1550.00	102269.00	HV	2070.00	128738.00
FW	1560.00	103019.00	HW	2080.00	128908.00
FX	1570.00	103699.00	HX	2090.00	129218.00
FY	1580.00	103919.00	HY	2100.00	129708.00
FZ	1590.00	104309.00	HZ	2110.00	129893.00

CROSS SECTION	HEC-2 CROSS SECTION	DISTANCE UPSTREAM OF POND 3 DIVERSION (feet)
IA	2120.00	130123.00
IB	2130.00	130473.00
IC	2140.00	130893.00
ID	2150.00	131673.00
IE	2160.00	131973.00
IF	2170.00	132653.00
IG	2180.00	133373.00
IH	2190.00	134048.00
II	2200.00	134483.00
IJ	2210.00	134738.00
IK	2220.00	135308.00
IL	2230.00	135758.00
IM	2240.00	136258.00
IN	2250.00	136968.00
IO	2260.00	137648.00
IP	2270.00	137968.00



FLOOD PROFILES

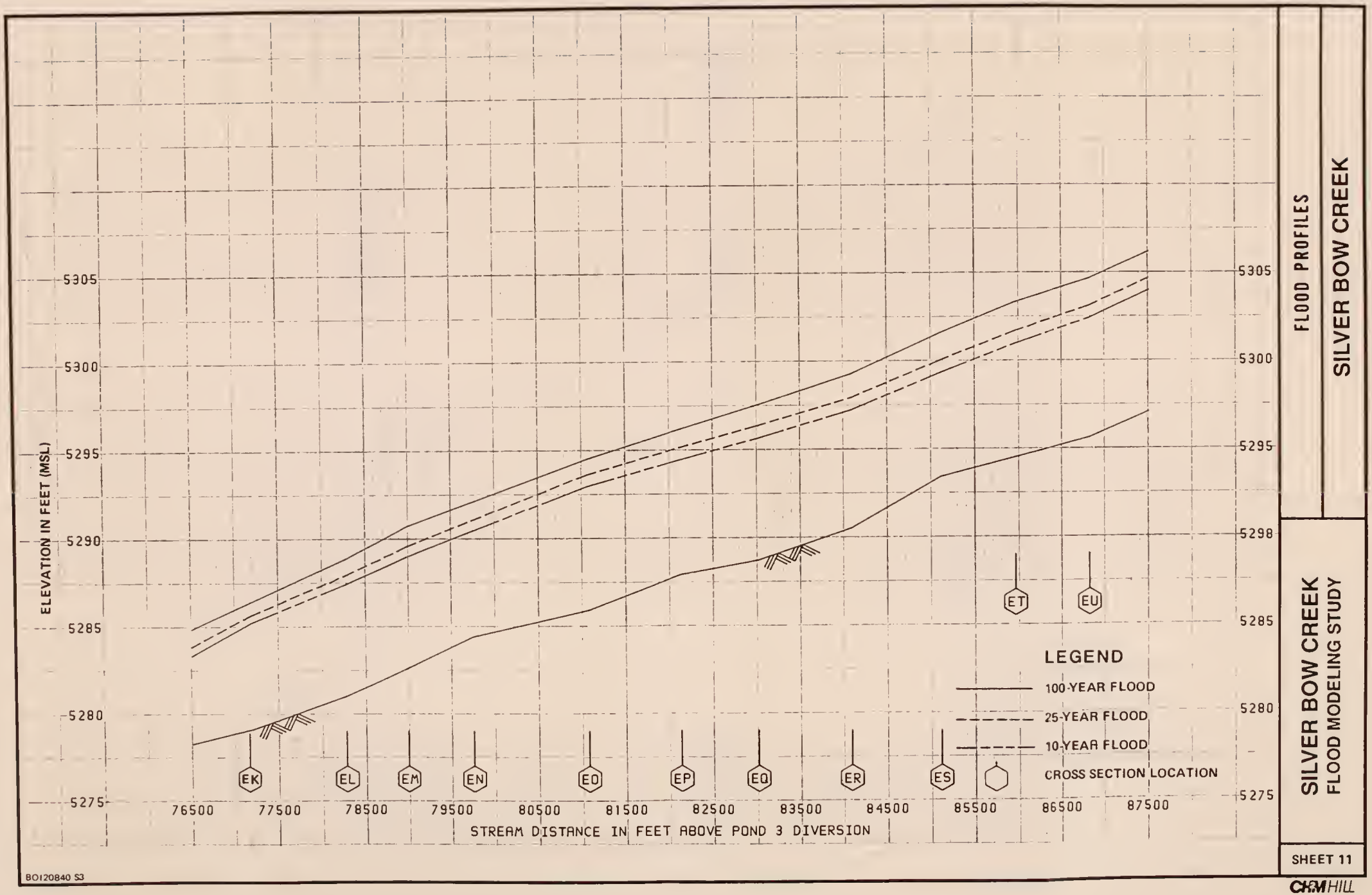
SILVER BOW CREEK

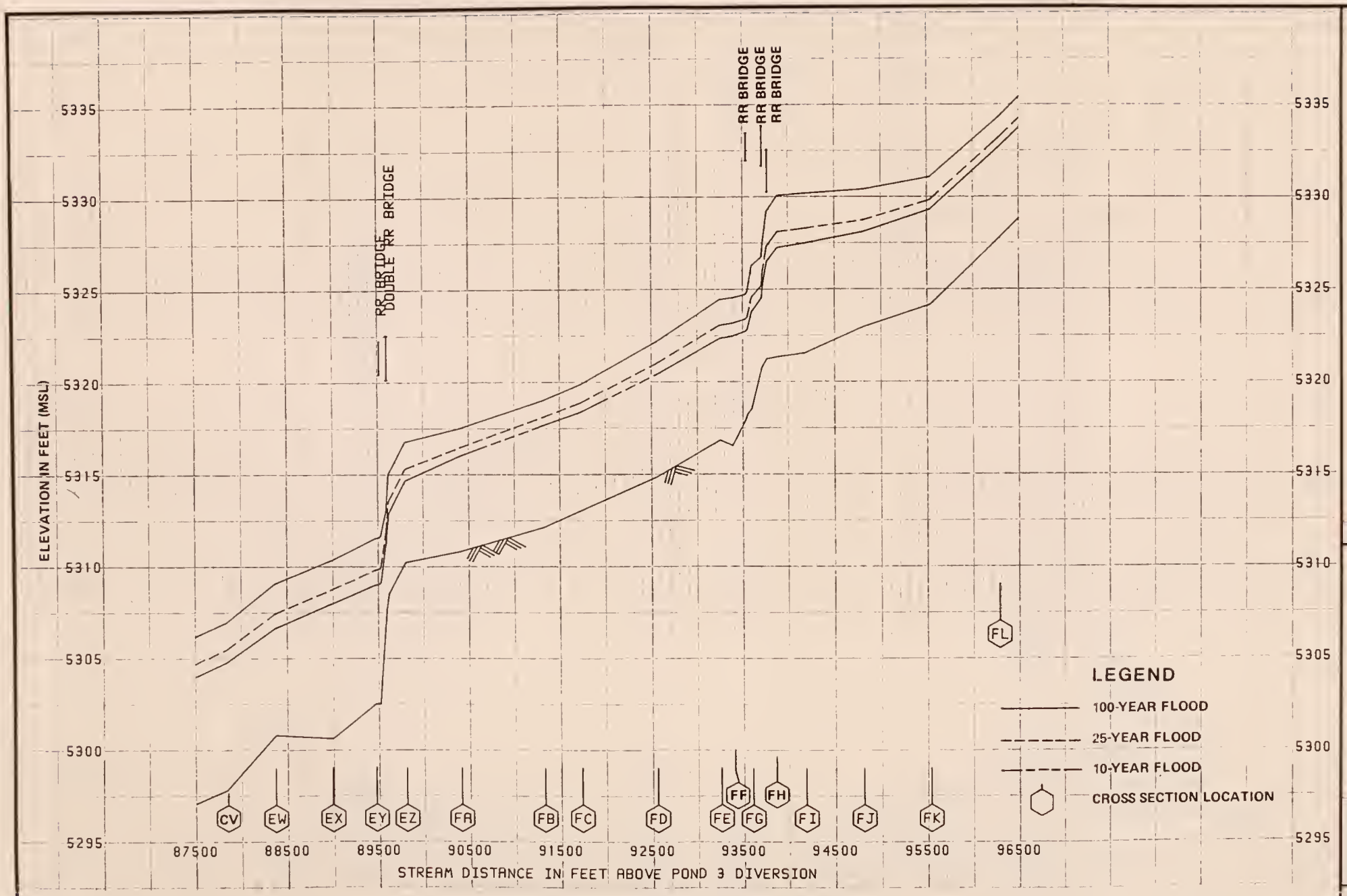
SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 10

BO120840 S3

CH2M HILL


ELEVATION IN FEET (MSL)
5305
5300
5295
5290
5285
5280
5275
76500
77500
78500
79500
80500
81500
82500
83500
84500
85500
86500
87500
STREAM DISTANCE IN FEET ABOVE POND 3 DIVERSION
EK
EL
EM
EN
EO
EP
EQ
ER
ES
ET
EU
LEGEND
100-YEAR FLOOD
25-YEAR FLOOD
10-YEAR FLOOD
CROSS SECTION LOCATION
FLOOD PROFILES
SILVER BOW CREEK
SILVER BOW CREEK
FLOOD MODELING STUDY
SHEET 11
BO120840 S3
CH2M HILL



FLOOD PROFILES

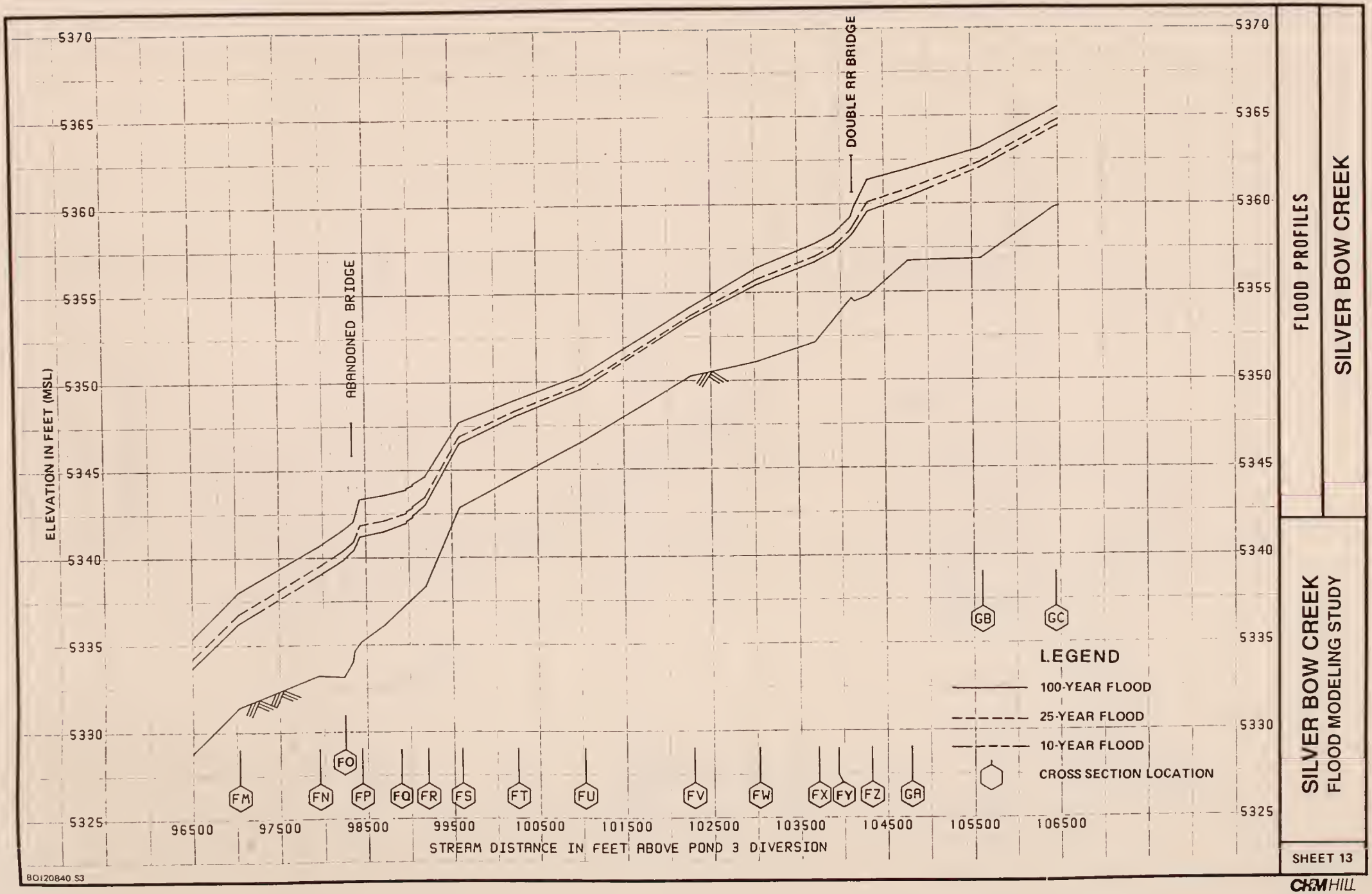
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 12

BO120840 S3

CH2MHILL



FLOOD PROFILES

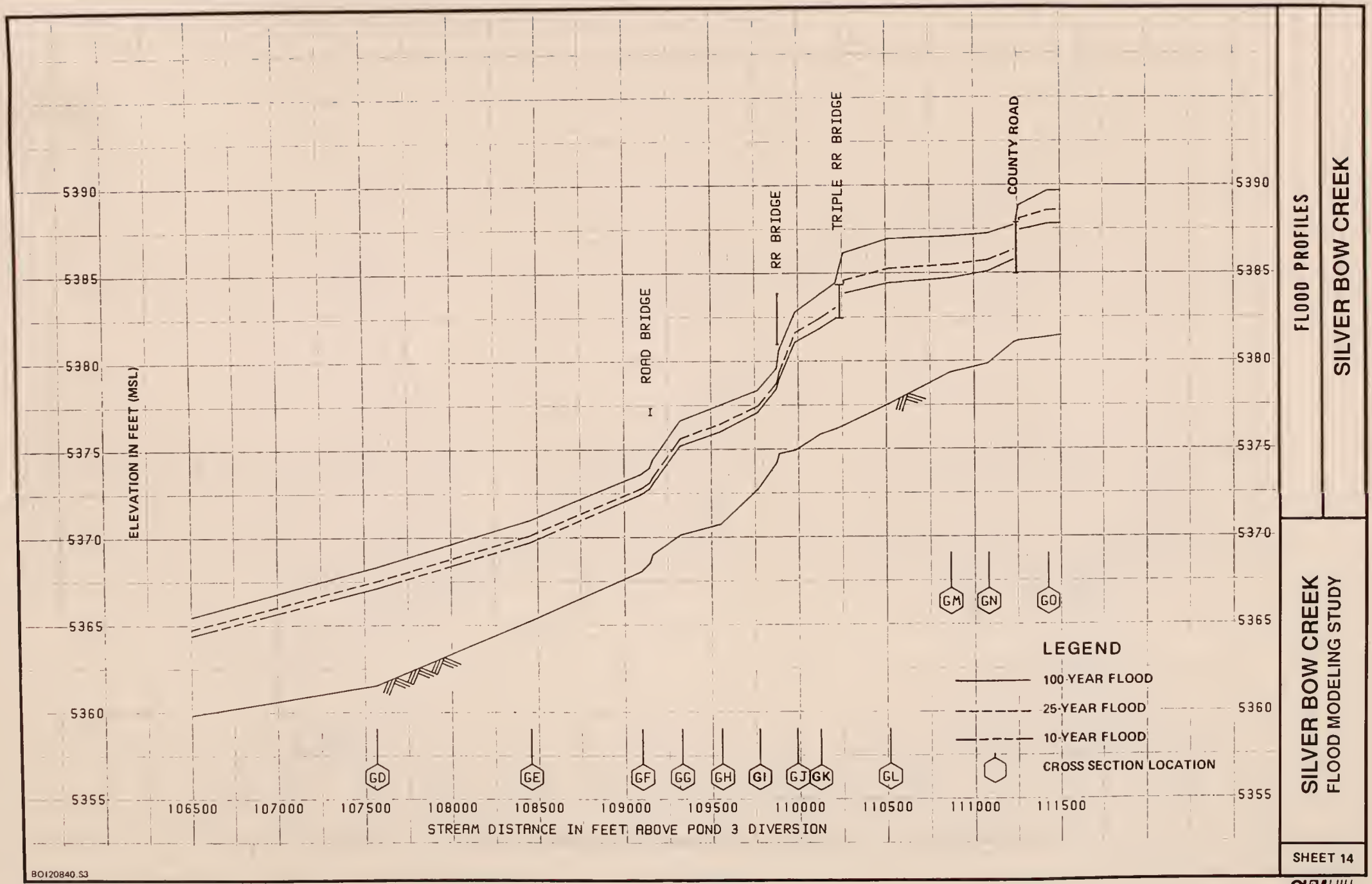
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 13

BO120840.S3

CH2MHILL



FLOOD PROFILES

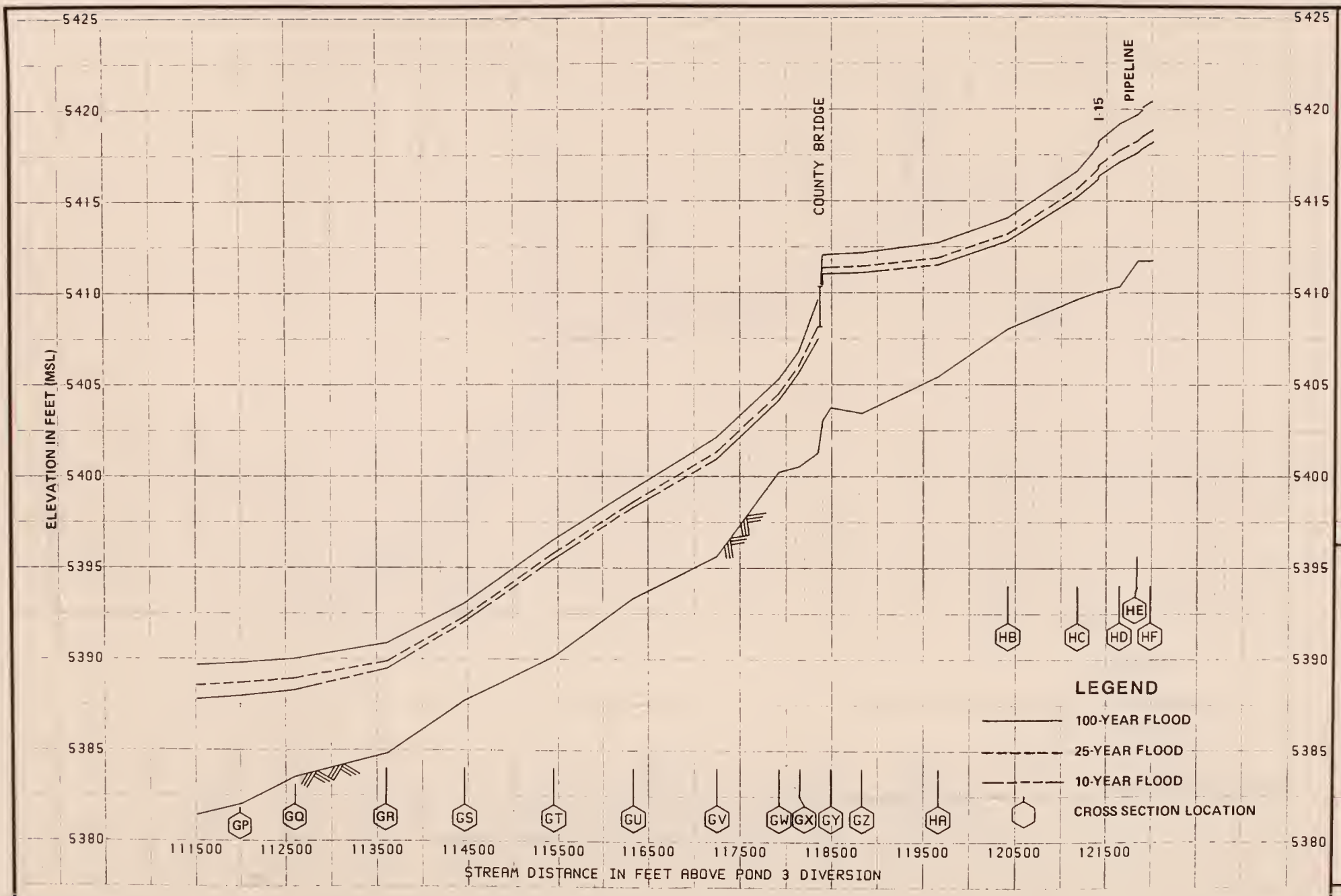
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 14

BO120840.S3

CH2MHILL



FLOOD PROFILES

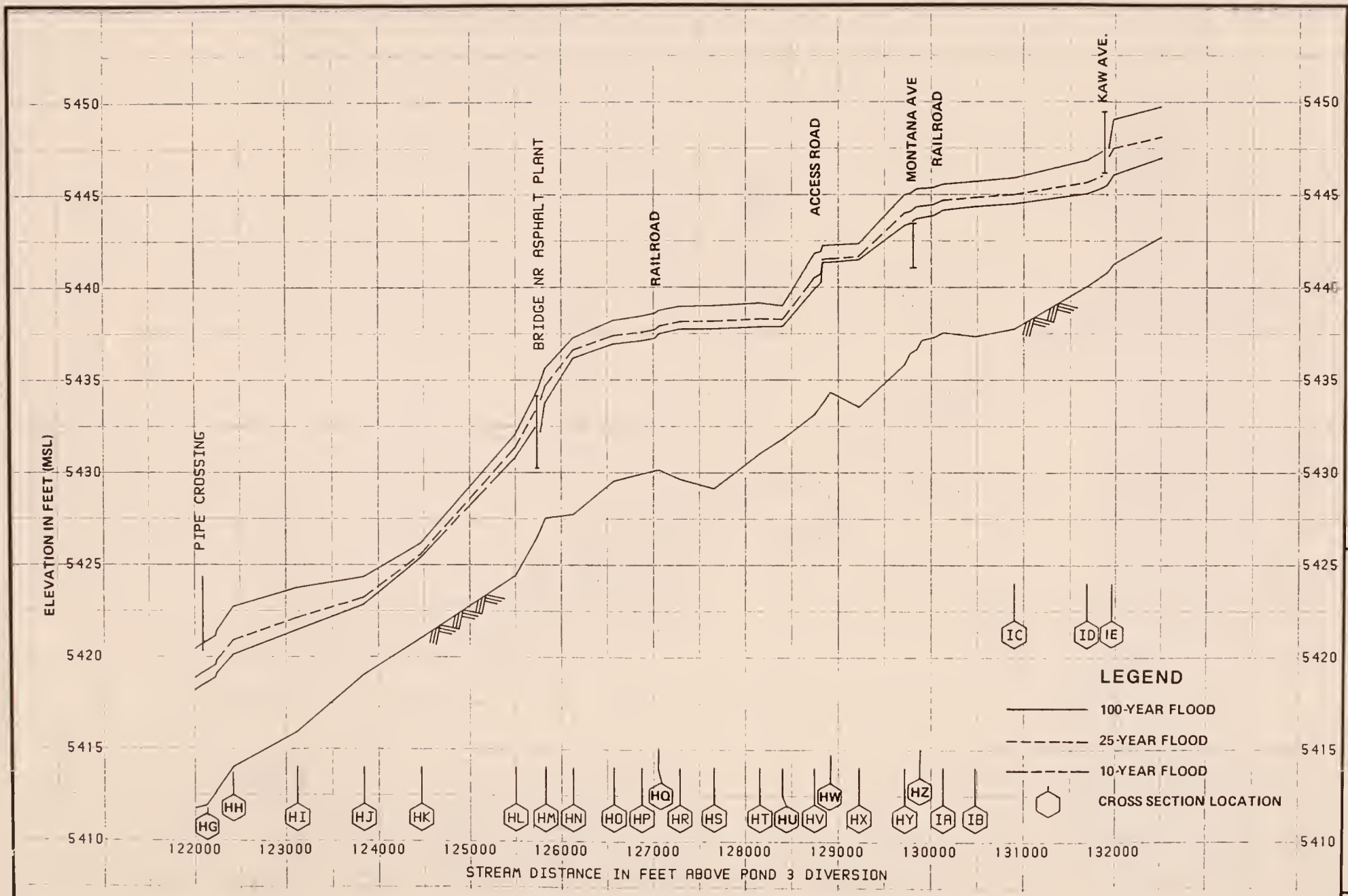
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 15

BO120840 S3

CH2M HILL



FLOOD PROFILES

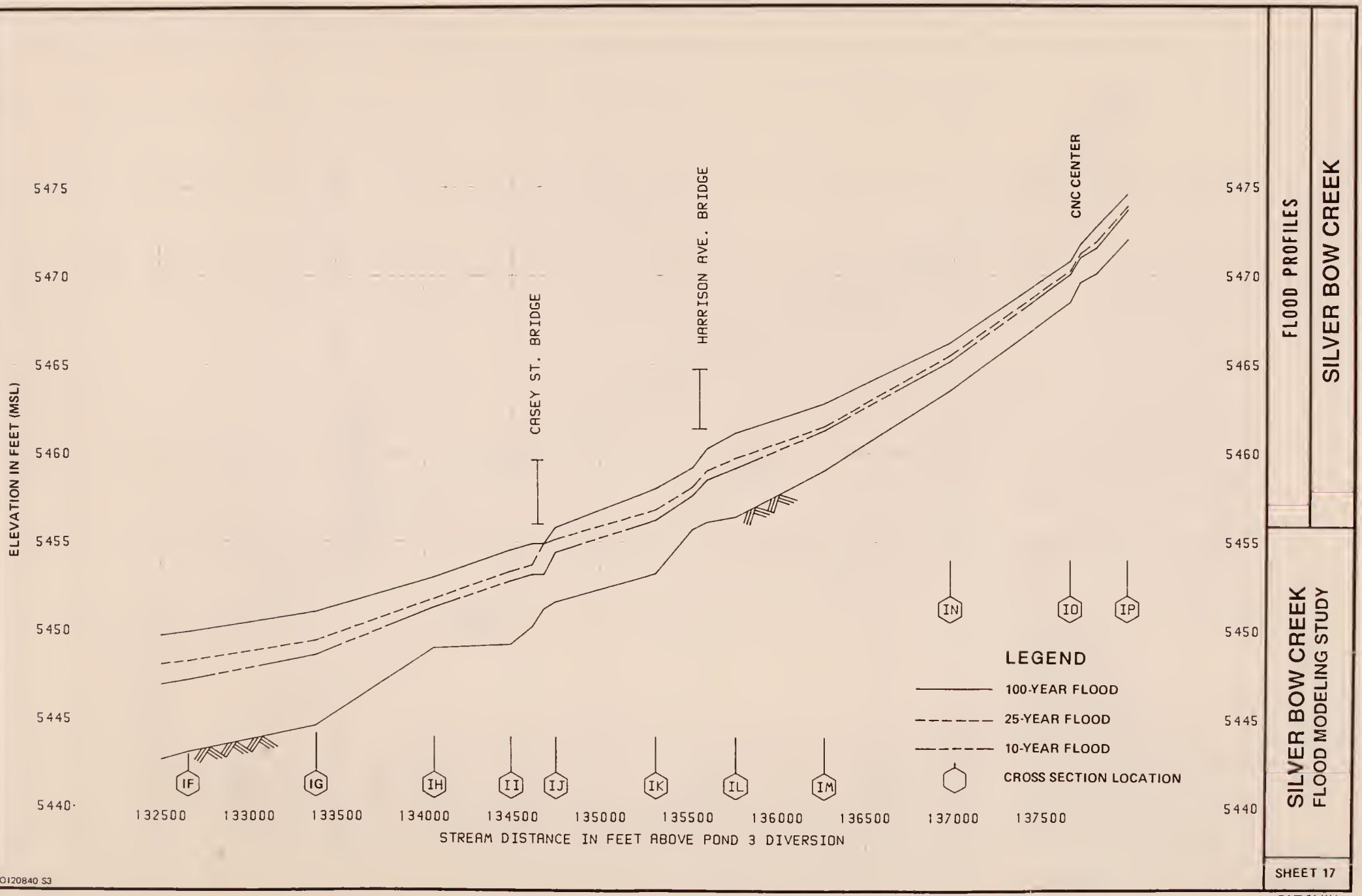
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 16

80120840.S3

CH2M HILL



FLOOD PROFILES

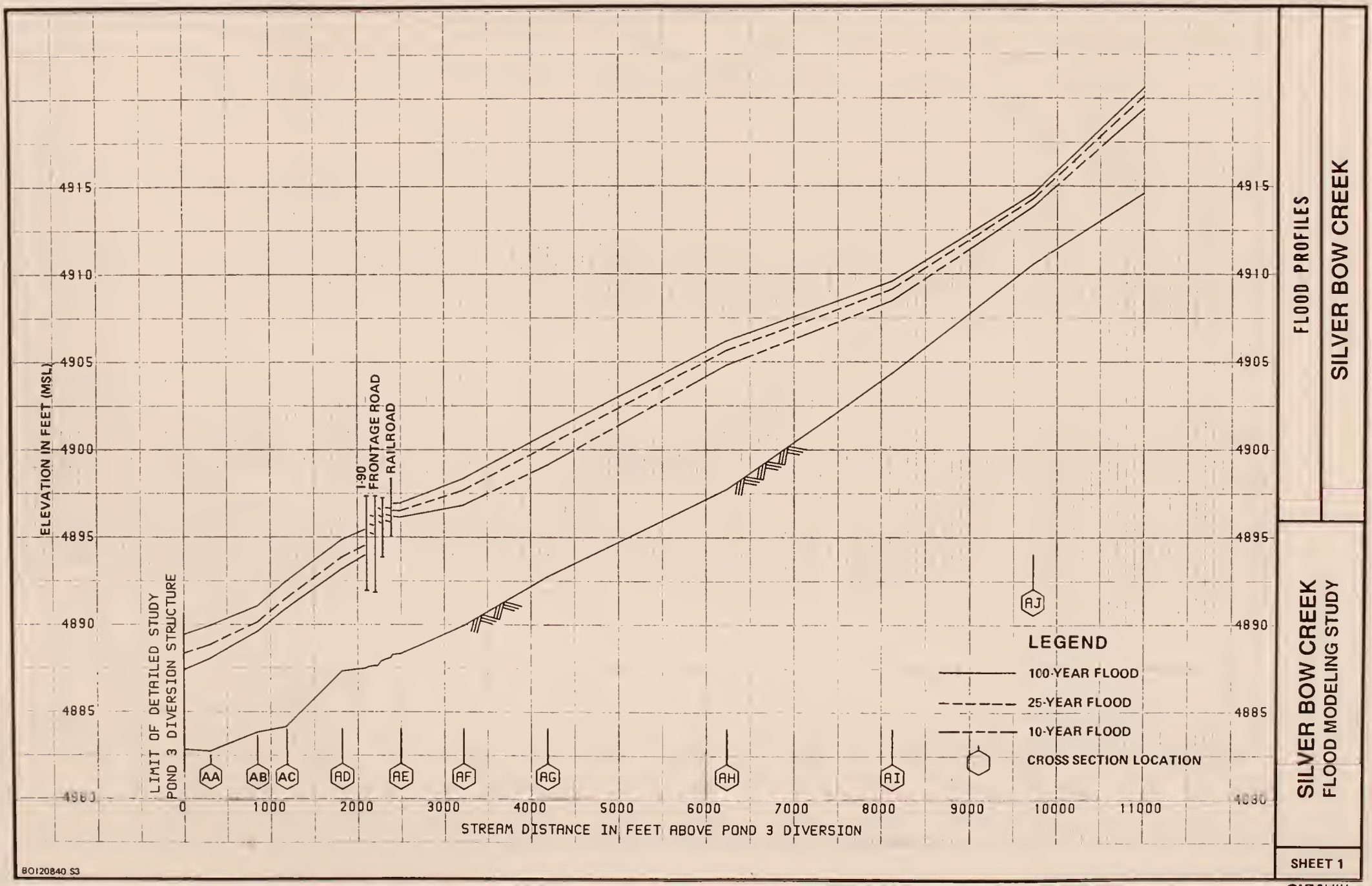
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 17

80120840 S3

CH2MHILL



FLOOD PROFILES

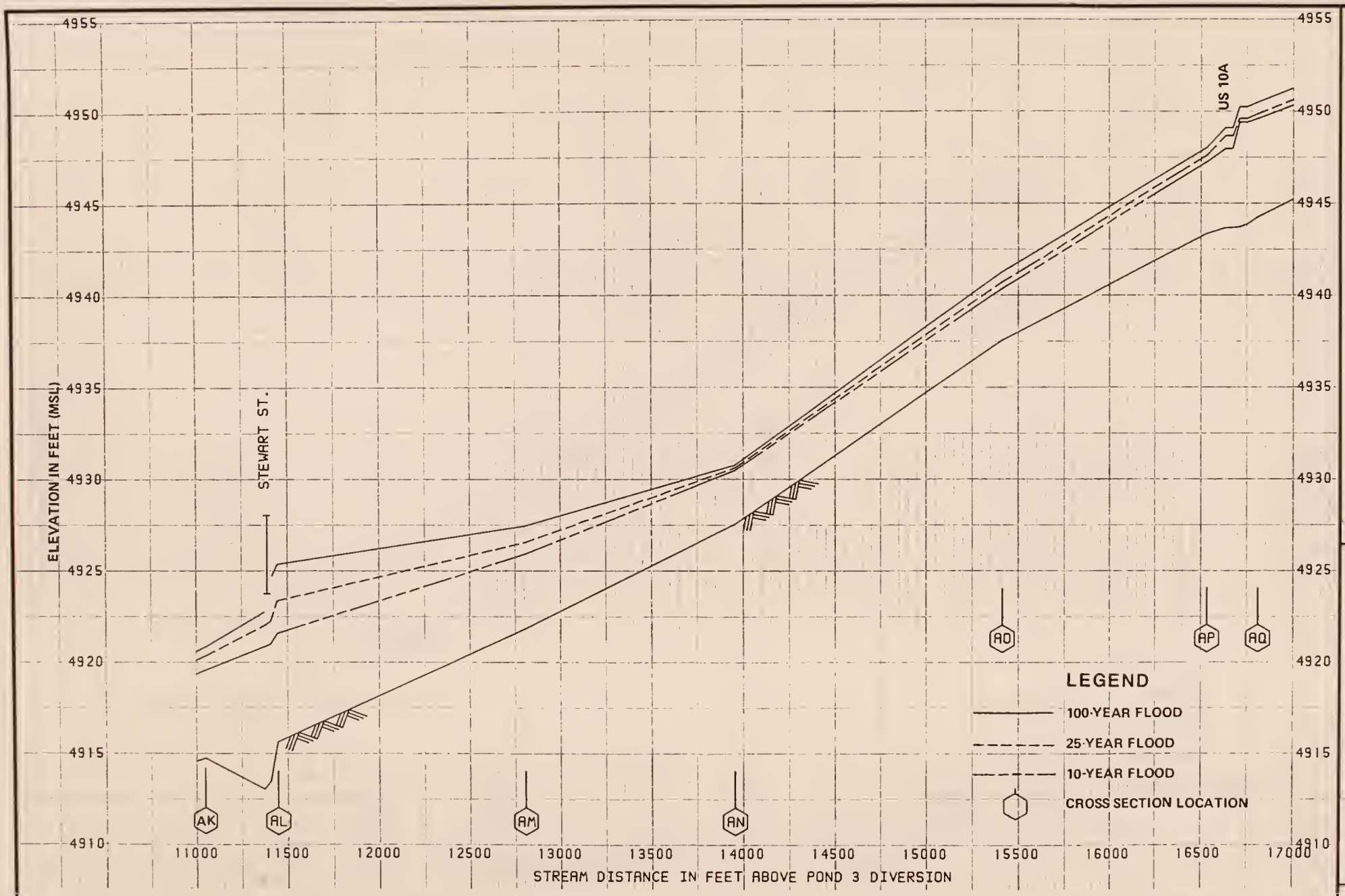
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 1

BO120840 S3

CH2MHILL



FLOOD PROFILES

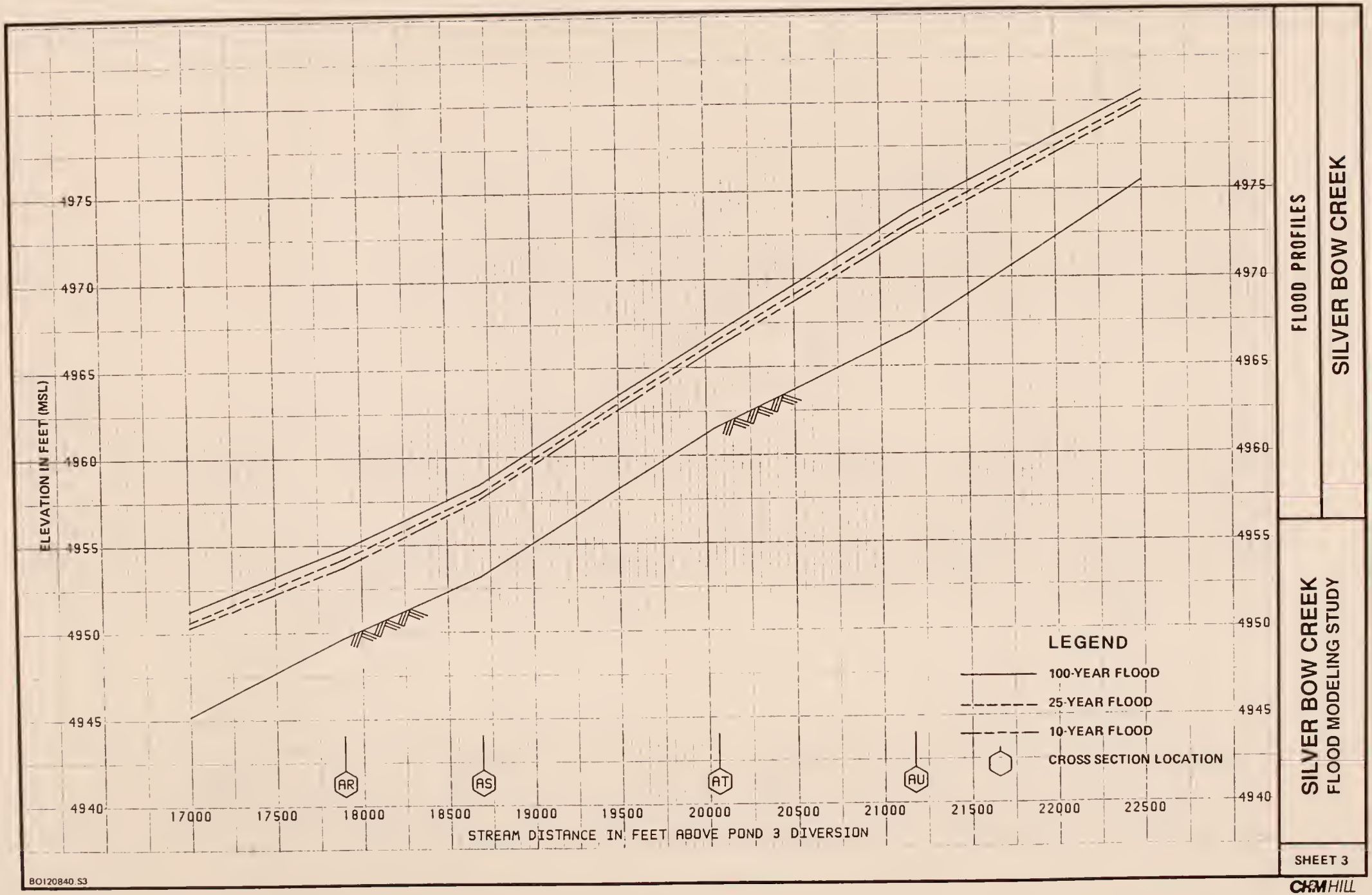
SILVER BOW CREEK

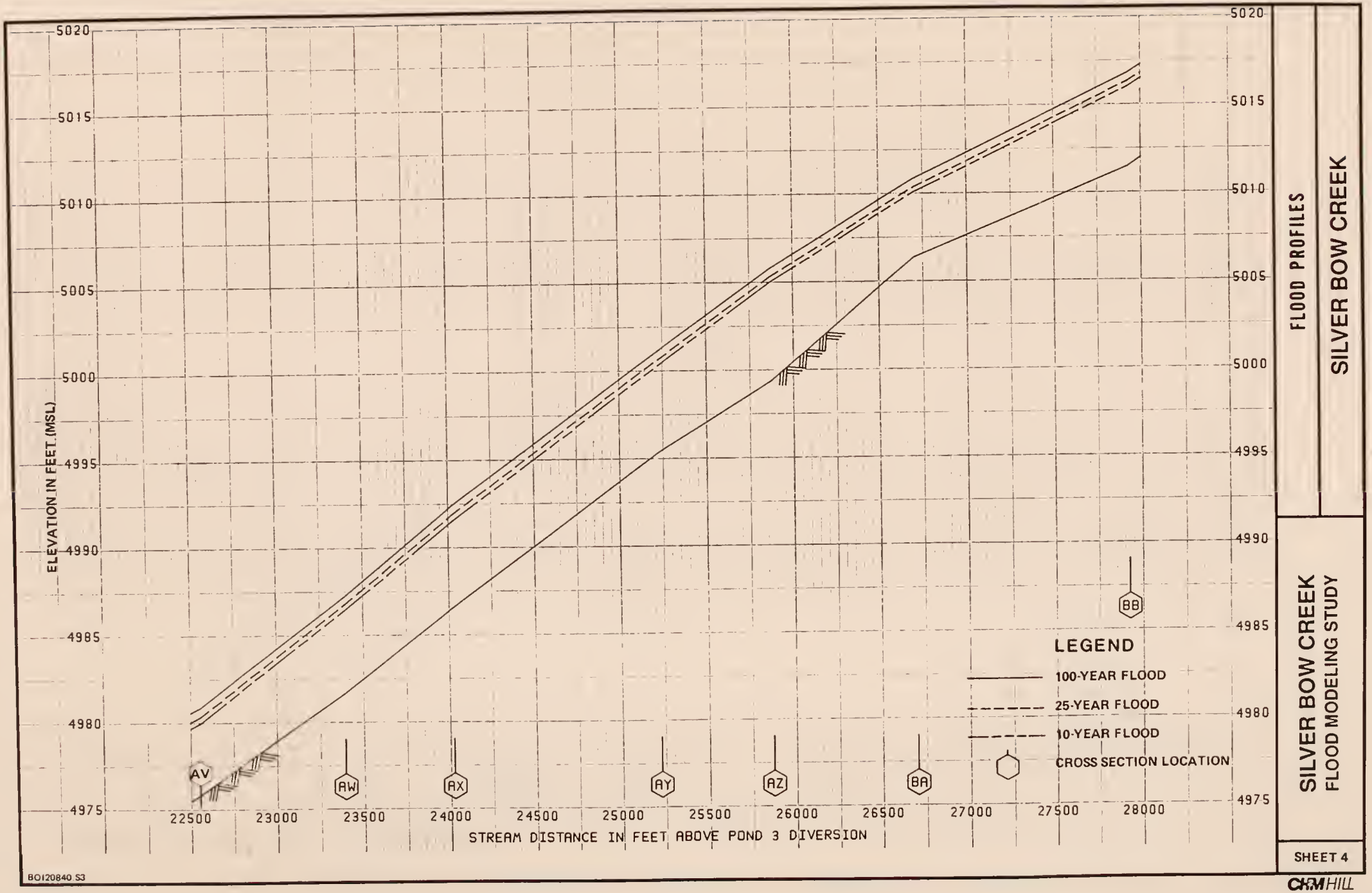
SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 2

BO120840.S3

CH2MHILL


ELEVATION IN FEET (MSL)
4975
4970
4965
4960
4955
4950
4945
4940
17000
17500
18000
18500
19000
19500
20000
20500
21000
21500
22000
22500
STREAM DISTANCE IN FEET ABOVE POND 3 DIVERSION
AR
AS
AT
AU
LEGEND
100-YEAR FLOOD
25-YEAR FLOOD
10-YEAR FLOOD
CROSS SECTION LOCATION
FLOOD PROFILES
SILVER BOW CREEK
SILVER BOW CREEK
FLOOD MODELING STUDY
SHEET 3
BO120840.S3
CH2MHILL



FLOOD PROFILES

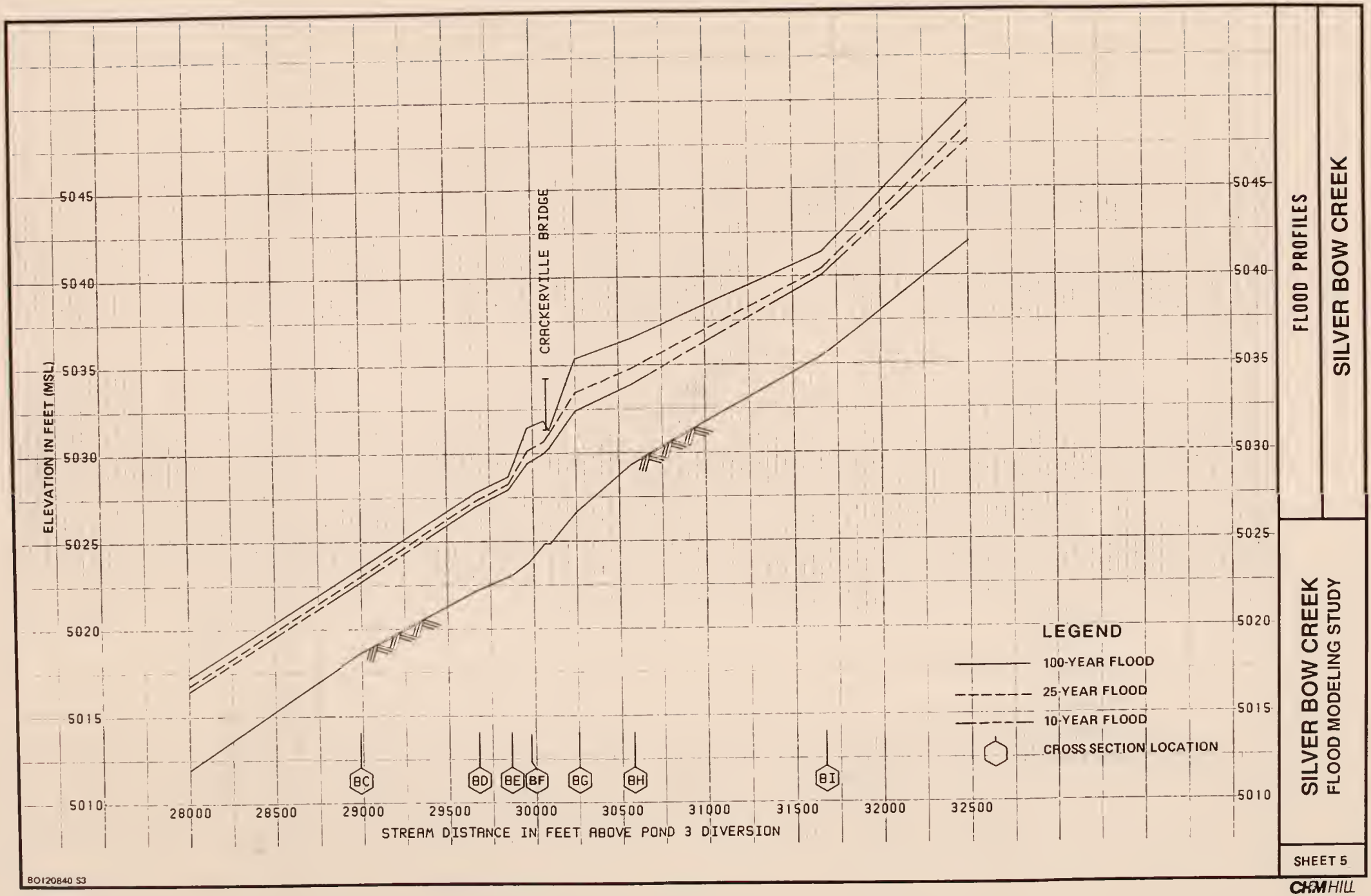
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 4

BO120840.S3

CH2MHILL



FLOOD PROFILES

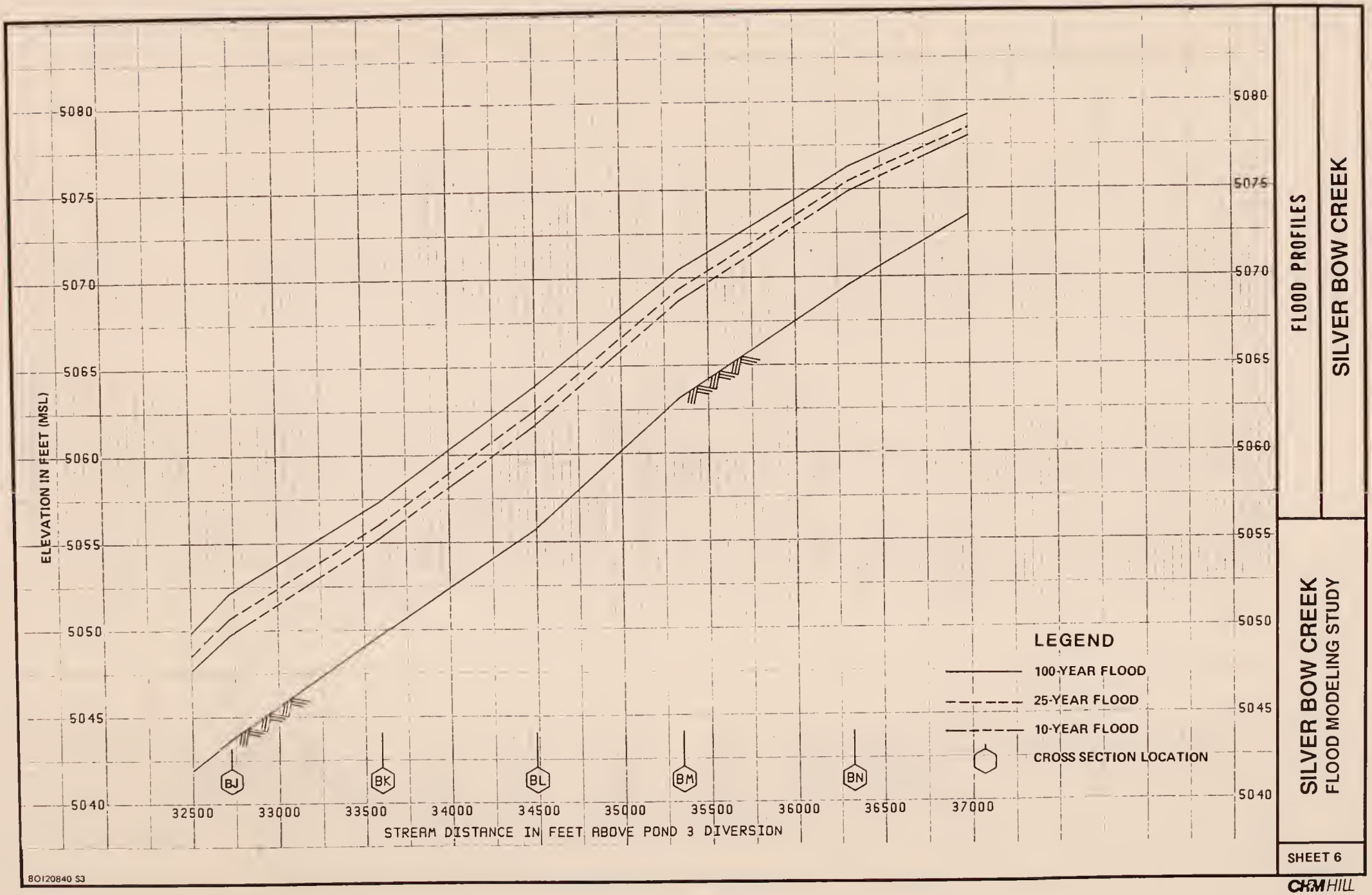
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 5

80120840 S3

CH2MHILL



FLOOD PROFILES

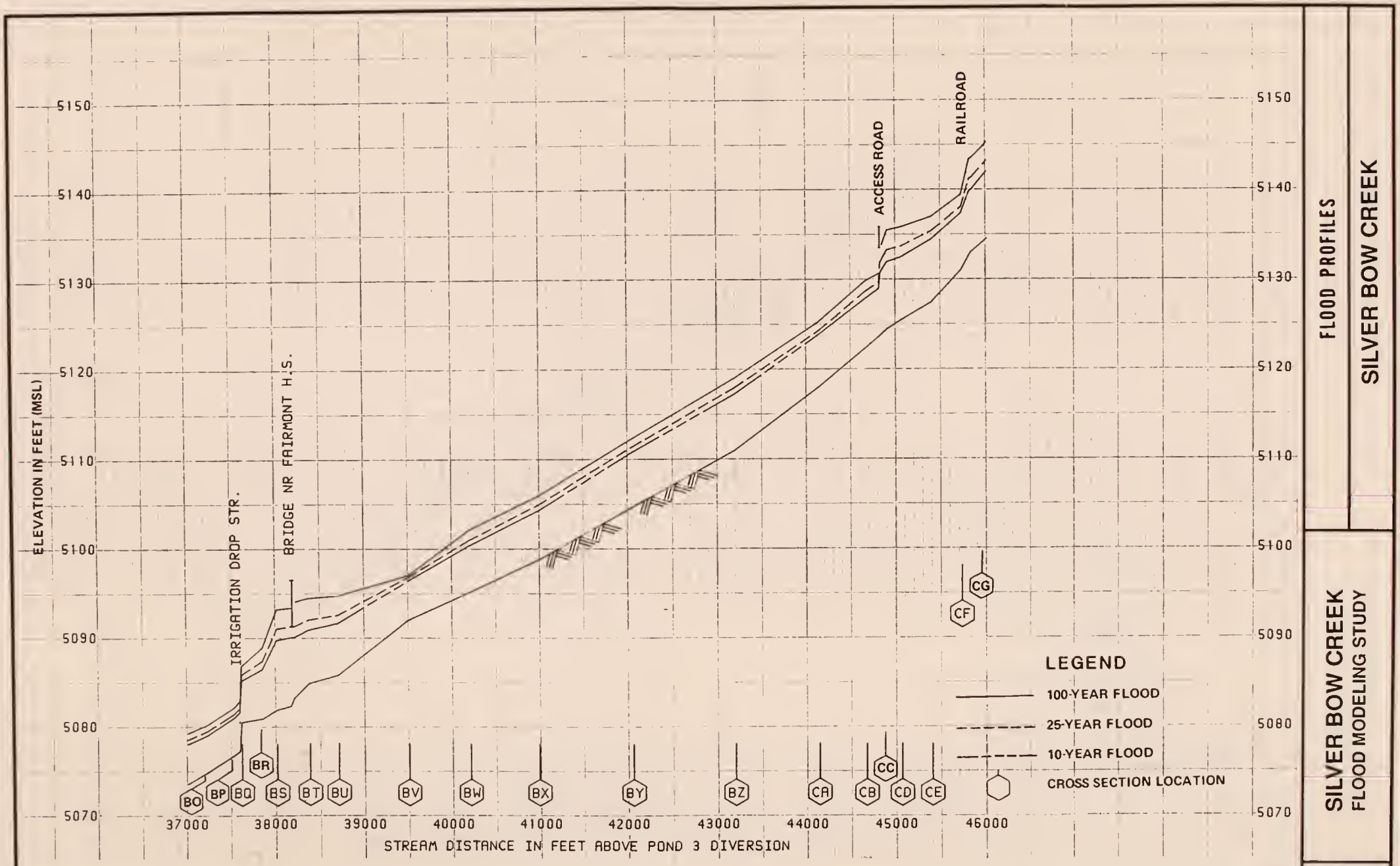
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 6

8O120840 S3

CH2MHILL



FLOOD PROFILES

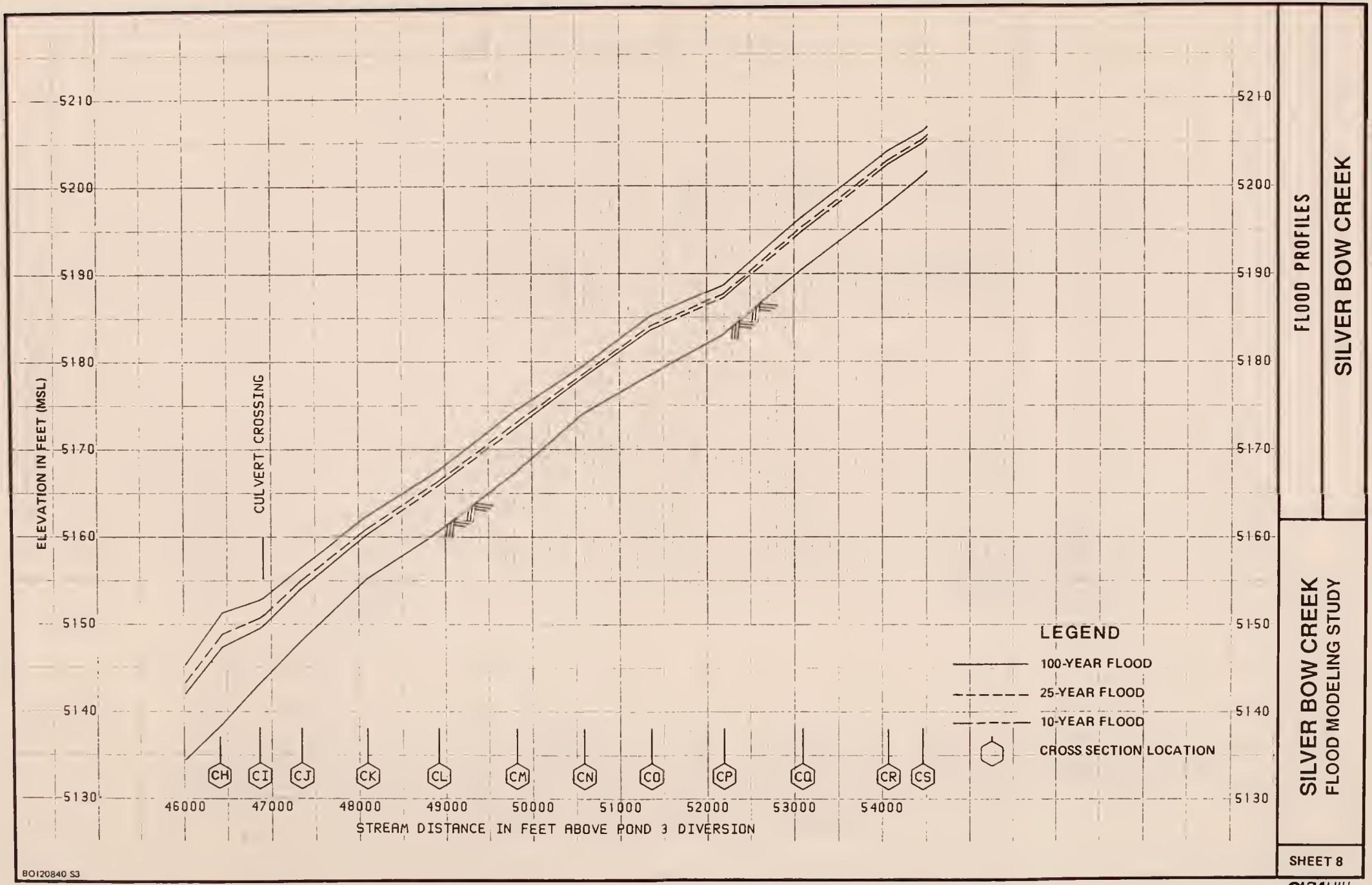
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 7

BO120840 S3

CH2MHILL



FLOOD PROFILES

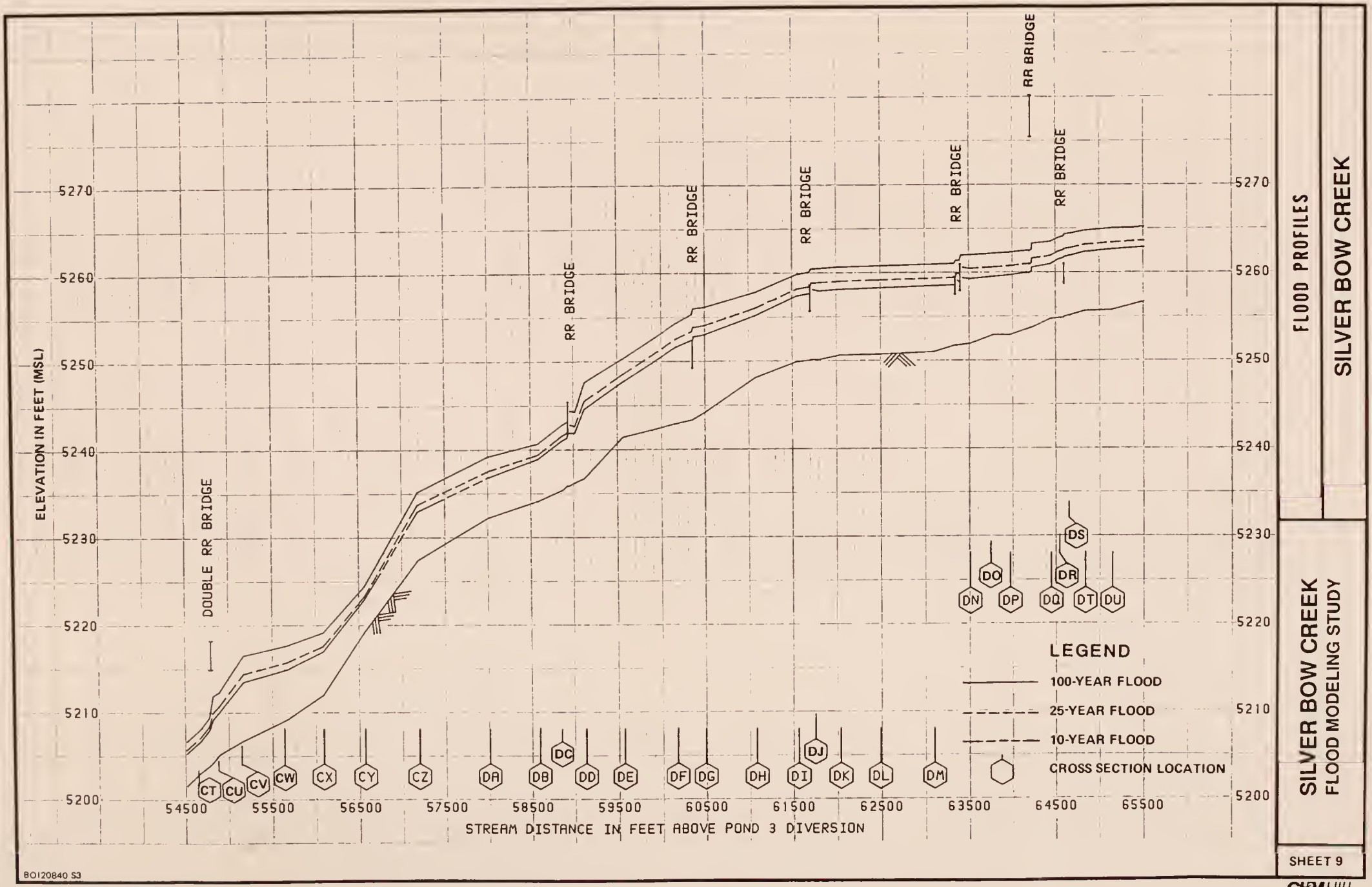
SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 8

BO120840 S3

CH2MHILL



FLOOD PROFILES

SILVER BOW CREEK

SILVER BOW CREEK
FLOOD MODELING STUDY

SHEET 9

BOI20840 S3

CH2MHILL